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A Bayesian decision theory approach to the investigation of standard cost deviations : an empirical study.

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A BAYESIAN DECISION THEORY APPROACH TO THE INVESTIGATION OF STANDARD COST DEVIATIONS: AN EMPIRICAL STUDY

A Dissertation Presented

By

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A BAYESIAN DECISION THEORY APPROACH

TO THE INVESTIGATION OF STANDARD COST DEVIATIONS:

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To my parents, Mr. & Mrs. Martin Sinclair, I dedicate this thesis. Their encouragement at an early age as to the importance of education made the completion of this study possible,

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ABSTRACT

A Bayesian Decision Theory Approach to the Investigation of Standard Cost Deviations: An Empirical Study (August, 1972)

Kenneth P. Sinclair, B.B.A., University of Massachusetts
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Having set the efficiency standard for a particular labor task in a manufacturing operation, an organization continually faces the question as to whether or not quantity deviations from this standard should be investigated. The objectives of this research are:

(1) to design a Bayesian decision-theory model which handles the above question

(2) to operationalize this technique in a real-world situation.

In terms of the specific model, attention is directed toward: (1) the establishment of the standard, (2) consideration of the true state of nature, and (3) payoff table including the costs involved with various decision choices.

Based on evidence in the literature, both the supervisor and engineer participate in setting the standard. By considering each of their estimates as to expected performance by the average worker as sampling distributions (obtained through a questionnaire), the two distributions are statistically combined resulting in the posterior mean equal to: (1) the standard and (2) the prior estimate as to the actual

performance level.

To answer the investigation question requires knowledge of the true state of nature, that is, the actual average performance level at the decision-point. In seeking to "zero-in" on this value, a posterior distribution is formulated from all available information, including the subjective prior estimate just obtained from the engineer and supervisor, and a sample of current data the size of which is determined by balancing the value of information with the cost of sampling.

The other major factor in the analysis is the payoff table including two acts (investigate, not investigate) and three distinct categories of states of nature. One state of nature designated "in control" represents a region bounded on either side of the standard by a control allowance (10 percent, for example). Performance below the lower control limit is deemed "unfavorably out of control," and above the upper control limit is marked "favorable out of control." Within each cell of the payoff table is a quantification of the costs involved for each combination of act and state of nature.

With the most recent posterior distribution determined and the payoff table formulated, the two are analytically combined to produce an expected cost of investigation and no investigation. The decision-rule is to select that act with the lowest expected cost.

From the application of this technique in a real-world manufacturing organization, the workability of the quantitatively-oriented procedures was treated. As the operationalization was performed, the following findings were made:

(1) By employing a unique means of participation in the standard-setting by both the engineer and supervisor, the acceptance of the standard as well as the understanding of the entire technique were gained.

(2) By treating the true state of nature in terms of expected performance at the decision-point, the technique was more clearly related to the control objective of preventing future problem areas.

(3) By including subjective evidence by the egineer and supervisor as to the true state of nature, the analyst had available more information by which to judge the optimum act.

(4) By formalizing into the model the category of performance marked "favorably out of control" (above the upper control limit), the analyst included a range of possibilities which could influence his decision.

(5) By being able to make reasonable estimates as to the cells of the payoff table, it was possible to combine these costs with the probability of their occurrence to obtain expected costs for each act.

CHAPTER I

A NEED FOR IMPROVED BUDGETARY CONTROL

1.1 Introduction

This chapter is intended to serve as an introduction to the research. It shall begin with a brief discussion as to the necessity for such research. Secondly, it shall outline the plans, purpose, and objectives of the proposed management tool. Finally, it shall suggest the contribution which the study makes to the existing accounting literature.

1.2 A Need for Effective Control

In order to justify the need for the proposed technique, there should first be some discussion as to the nature of control. What is control? Why are organizations so concerned with it? Finally, have companies been able to handle the control process effectively? This section shall explore these questions.

Most often the success of a business is dependent on its management. Whatever the goals of the organization, it is management which must carry them out. To accomplish this end, it must establish a relationship with other members of the organization. As G. H. Hofstede[1] points out, the fundamental organizational link between the manager and other people is the control process. To be successful, its control process is "the process by which one element (person, group, machine, institution, or norm) intentionally affects the actions of another element."

For management to affect the action of its workers, it must establish plans which formally set in motion what is expected of them. Henri Fayol,[2] in discussing the nature of control, explains that it is more than merely persuading a course of action. In addition, it is seeking to assure that what is done will be what is intended. Fayol points out that the goal of the process is:

> Verifying whether everything occurs in conformity with the plan adopted, the instructions issued, and the principles established. It has for object to point out weaknesses and errors in order to rectify them and prevent occurrence. It operates on everything, things, people, actions.

Although management is not able to control the past, it wishes to take steps to avoid recurrence of unwanted experience in its plans for the future. Towards this end, there are three fundamental aspects of the control process:

1. Establishment of plans--This is the expectation of the future which reflects the organization's goals and objectives.
2. Appraisal of performance--This is the measurement of actual performance.
3. Correction of deviations[3]--This is the process which seeks to eliminate the causes for the differences of actual performance and established plan.[4]

Many companies try to establish such a control system, yet fail to handle adequately the three phases stated above.

There are several reasons for this failure:

1. <u>Failure to reflect the nature and needs of the activity</u>--The control tools of the sales department will vary from those of the manufacturing department and in turn of the finance department. Care must be taken in expressing the standards in applicable terms.
2. <u>Failure to report deviaitons quickly</u>--If a manager discovers a deviation in December concerning an inefficiency from February, although the information may be of some value, the real opportunity to eliminate the deviation may be gone.
3. <u>Failure to use flexible controls</u>--With the possibility of changed plans or unforeseen circumstances, the controls must remain flexible. If, for example, an expense budget is based on a certain level of sales, and this sales level does not occur, the planned expenses must be evaluated on the basis of the adjusted sales figure.
4. <u>Failure to reflect organization pattern</u>--If a manager is responsible for the tasks of his operation, then he must be the focal point for only those costs which pertain to his department and to which he can control. If costs are arbitrarily allocated without this regard, then actual costs may be out of line without the manager's knowing whether the deviation

has been caused by something within his control.

5. Failure to consider the cost of the control system--Many companies maintain elaborate charts and detailed analysis which may be more costly to install and maintain than any savings caused by the control mechanism.
6. Failure to establish understandable controls--If the managers and subordinate workers are unable to understand what is expected of them, then it is hard to have them strive for the established plan.
7. Failure to assure corrective action--Perhaps the greatest failure is the lack of knowledge as to the real cause for deviations from standard. Therefore, without knowing the cause of the deviation, necessary action cannot be undertaken.[5]

Any success for an organization's control process depends upon the degree to which the considerations above are met. At the organization to which this theoretical model will be applied, two elements of cost, direct material and direct labor, can illustrate the impact of the above considerations.

In terms of direct material, the organization purchases the raw material needed to manufacture many types of brushes. Engineers and division managers establish standards as to how much raw material will be necessary to manufacture a certain number of brushes. Once the material usage standard is established, much time and effort is consumed in preparing monthly statements as to the actual results.

Table 1

Raw Material Usage Deviations
For the Year 1971 (In Thousands of Dollars)[6]
At the Organization Under Study

	Standard	Actual	Deviation
January	$231.7	$208.0	$23.7
February	163.3	148.1	15.2
March	178.0	177.5	.5
April	175.5	177.9	-2.5
May	188.4	179.4	9.0
June	196.8	197.3	-.5
July	108.9	106.5	2.3
August	203.3	201.7	1.6
September	230.7	217.3	13.4
October	225.8	241.0	-15.2
November	202.7	198.4	4.3
December	223.2	227.0	-3.8

Note:
Standard = Standard units x standard price
Actual = Actual units used x standard price
Deviation = Standard - actual

Taking a look at Table 1, one sees that the deviaitons for the year 1971 have fluctuated tremendously. The numbers range from a favorable deviation of $23,000 to an unfavorable deviation of $15,000. Management simply has no idea what to expect in 1972. Table 2 reveals more of the same.

Table 2

Raw Material Usage Deviations
First Three Months 1972 (In Thousands of Dollars)[7]
At the Organization Under Study

	Standard	Actual	Deviation
January	$205.1	$232.0	$-26.9
February	275.2	285.1	10.2
March	247.3	239.2	8.1

Considering the above results in terms of effective control, the following is noted. The reports arrive no sooner than monthly. Usage for several types of raw material is aggregated so that one cannot determine which brushes are causing more usage of material. Indeed, there is no mention at all of reasons for the deviation. Who shall be responsible for the deviations? Will it be the first shift supervisor, second shift? Can, in fact, anything be done to correct the deviations? All these statements, all these questions suggest a need for more effective control. The deviations for last year have not become more consistent, and there appears no real indication that they will.

With direct labor standards, this organization maintains much tighter control, and therefore some of the failures discussed above do not appear. Checks on the standards are made every two hours of work, significant deviations are recorded per operator, and corrective action when taken is noted.

Table 3

Direct Labor Deviations
For the Year 1971 (In Thousands of Dollars)[8]
At the Organization Under Study

	Standard	Actual	Total Deviation	Efficiency Deviation
January	$166.5	$148.5	$18.0	$ 8.1
February	151.0	132.6	18.4	7.8
March	149.8	131.1	18.7	8.8
April	135.0	122.3	12.7	9.9
May	123.6	111.7	11.9	10.8
June	135.2	133.4	1.8	7.6
July	33.6	39.9	-6.6	4.5
August	115.1	102.7	12.4	9.3

Table 3 (cont.)

September	107.2	98.5	8.7	7.8
October	102.3	91.1	11.2	9.2
November	100.9	9.31	7.8	7.1
December	109.0	93.6	16.3	10.0

Note:
Standard = Standard units x standard price
Actual = Actual units used x actual price
Total Deviations = Standard-Actual
Efficiency Deviation = (Standard units - Actual units) x Standard price

As is pointed out in Table 3, the fluctuations (with the exception of the summer vacation months) are consistent. There is only a $3000 range for the efficiency deviations. This indicates a better control, for management is able to predict reasonably well what future performance will be.

Because of the marked appearance of all favorable deviations, there exists some suspicion as to credibility of the standards. Perhaps, the workers find the standards so loose that they produce at less than the optimum pace. It may be that this situation is already optimal. The point is that for effective control to exist a constant reevaluation of the standard must take place. The control process must maintain a mechanism to handle this reevaluation.

One final point about direct labor control. Just because the organization spends a sizeable amount to check for deviations, this does not mean that there is more effective control. There comes a point where the added tightness of the control is unnecessary. At this organization checks were formerly made on a one-hour basis with deviations similar to ones found in Table 3. Perhaps in the future, it may be advantageous to have four-hour checks (at less cost).

In implementing the model at this company, the concern shall be to improve upon the existing control procedures already in practice. Working with a particular aspect of the labor function, attention will be directed toward a control process which in terms of the characteristics set forth in this chapter is in fact somewhat effective. Nevertheless, the task shall be to do even better, to get a more meaningful look at the deviations and ultimately to reduce the deviations themselves.

1.3 Brief Sketch of the Research

This study shall consider the budgetary control system in terms of the question as to whether or not a discovered standard cost deviation (expressed in units) should be investigated. Organizations spend much time and effort establishing standards for their elements of cost and then tabulating the actual results so that they can be compared to these standards. The problem arises when top management sees the deviation and is unaware as to the next course of action. Indeed, the basic issue becomes whether or not anything can be done or in fact should be done with a deviation.

In considering the investigation phase of the control process, attention shall relate to this one item in terms of its relationship to the entire system, since it shall be shown that each aspect of the control process (both preceding and following investigating) must be clearly understood in order to face the investigation decision. Therefore, although the literature survey shall concentrate on the investigation phase of the control process, discussion shall relate to other important, related items.

As the literature shall point out, there exists the need for a more clearly defined decision-rule for management to follow in this area. As a result, the final act of budgetary control has inadequately been carried out. If management fails to investigate a discovered deviation (allowing excess costs to continue) or on the other hand spends more to eliminate a deviation than the deviation itself, then these costs eat at the profits of the operation.

To handle this problem as to whether deviations should be investigated, a decision theory model has been formulated. For each segment of a manufacturing operation where a supervisor in charge employs the existing control mechanism to handle deviation from standard, this model serves as a supplementary device to enable the supervisor and his boss (the production head, for example) to pinpoint problem areas within the supervisor's particular responsibility.

Therefore, given the control mechanism at hand (whether good or bad), an analyst working for the supervision decides at the end of a given period (one month, for example) whether or not actual performance is close enough to the standard.

It should be mentioned that if the daily control system is effective, the technique will advise that there is little need to make any major investigation. In effect, the device acts as a check on the existing control system. If an investigation is required, then the production head can authorize it and in addition hold the supervisor accountable.

Within a manufacturing setting, this study shall select one particular item to be manufactured. It shall key on one element of cost, namely direct labor, and follow only one labor requirement for the item under study. Because quantity deviations would probably be more volatile than price deviations, it was decided to key on a labor efficiency standard. Therefore, as a first step the study shall examine the establishment of the efficiency standard (in units) for this one specific labor requirement, considering such influences as the tightness or looseness of the standard and the behavioral impact of participation in the standard-setting.

Once the standard itself has been determined, the analyst using the technique shall note a number of units above and below the standard to serve as an allowable deviation from standard. If the true state of nature, that is, the actual level of performance, does in fact lie within the limits of the constructed region, then the system is deemed "in control." If it is below the lower control limit, it is "unfavorably out of control." If it is above the upper control limit, it is considered "favorably out of control."

Since the analyst does not know for sure in which area actual performance does lie, he must assess probabilities for the three states of nature (faborable, unfavorable, or in control). Therefore, using subjective and objective information as to the actual performance level, both initial and later revised probability assessments are made as to the true state of nature. In Chapter IV (the model itself) a detailed explanation of each factor discussed above shall be made.

Merely recognizing that the system is out of control does not yet answer the question as to whether a deviation from standard should be investigated. To complete the decision-making process, a payoff table must be formulated which incorporates all costs involved with the investigation question. If, for example, the company were to learn that it would lose more by correcting an observed deviation than by doing nothing, then it would, of course, be advantageous not to correct it. This model includes these costs, quantifies them, and presents an expected cost for an investigation and no investigation. The decision-rule is to select the course of action with the lower expected cost.

Formulating this technique from the existing literature by applying the different disciplines such as behavioral science, statistics, and accounting has led to a theoretical model which has not been tested in the real world. Today, academicians are presenting theories concerning the business world which when tested in a real-life setting prove unacceptable. This study shall seek to extend the decision model from its theoretical framework to an application in the real world.

Working with a local company which manufactures different hair brushes, this study shall provide an in depty analysis of a proposed implementation of the model to their operations. Although the analytic framework is applicable to any cost element of the company (material, labor, or overhead), its usefulness will be demonstrated on the direct labor component of cost because of the ready accessibility of data.

To begin, one particular hair brush (brush 612, for example) shall be selected. Given that brush, attention shall be directed on one labor requirement necessary for the completion of that brush (the heat-sealing operation). After establishing the standard and control limits for the number of units to be completed (as to the appropriate task), the analyst indicates a prior estimate as to what actual performance will be (obtained through a questionnaire to the engineer and supervisor). Then, by sampling the actual data (the model shall determine the optimum sample size), a sample estimate as to the actual performance level is made. Using statistical theory, the analyst combines the two estimates and arrives at an updated probability assessment as to the true state of nature.

Once this probability assessment is formulated, consideration shall be made of the costs of investigating a deviation and the opportunity costs for not investigating. Coupling these costs to the probabilities for the deviations, an expected cost for investigation and no investigation shall be computed. Whichever expected cost is lower, the corresponding act shall be the one desired. What results is a decision-rule for management to use to answer whether the deviation should be investigated.

In implementing the model, this study shall include a computer program which shall enable the company to:

A. Input: (1) all available information as to the true state of nature including the engineer's and supervisor's estimates, (2) the standard and control allowance, (3) the various items in the payoff table.

B. Calculate the most updated estimate as to the true state of nature.

C. Calculate the expected costs for the two acts: Investigate and not investigate.

D. Calculate the value of information at the decision point based on the information at hand.

E. Print out the optimum decision.

As a final note to this study, in the last chapter there will be some discussion as to the effectiveness of this model. In analyzing the technique, certain questions will be posed:

A. Has the standard been adequately determined?

B. Is the true state of nature viewed more correctly than before?

C. Has all available information been included in the analysis?

D. Has the payoff table been handled properly?

1.4 Contribution to the Accounting Literature

The above section has given an indication of the objectives of this particular study. This section shall explore the contributions which are believed to be made by this research.

In terms of the theoretical model, there has been an attempt to extend the work already existing in the literature. First, by placing much concern on the behavioral aspects of participation in the setting of standards, this standard-setting aspect of the control process has been treated somewhat differently than before. As shall be seen later, one aspect of the model is an initial statistical distribution which represents what a supervisor believes the performance shall be for a particular labor function given a certain time period. Considerable emphasis has been placed on the determination of this distribution according to behavioral theories expressed in the literature.

With statistical theory, there is much emphasis on Bayesian statistics to update the probabilities. Once the statistical distribution (mentioned above) is determined and probabilities assigned for certain segments of the distribution, then the sampling of actual data in the plant will be used to revise the initial probabilities. The process continues until the cost of sampling becomes greater than the increased information derived from the updating of the probabilities.

Besides the additions as suggested above, the proposed model presents a synthesization of many fragments of existing literature. By synthesizing many of the individual techniques which are mentioned in the literature, the attempt has been to create a workable management tool which could be applied in the real world. The result is an interdisciplinary approach to the deviation investigation question.

Perhaps the greatest contribution lies with the analytic framework applied to an actual situation. Throughout the literature there has been a lack of discussion as to real problems which might be encountered from such an application. There has been little to suggest how many of the literal representations in the model could be actually quantified. There was much concern as to why there had been no comprehensive study which did apply the theory. Was it because parts of the model could not be quantified realistically? Was it because the costs to implement the proposed technique would be too large for its apparent advantages? Finally, was it because the business world was too skeptical of the sophisticated theories in the model? This study will seek to answer these questions.

Professor Horngren in speaking of the change in the accounting discipline of the future suggests that the accountant's role will not be merely to present information for its own sake.[9] Data by itself serves little purpose unless it is related to some objective, some decision which must be made. In his article, he speaks of some who predict doom for the accounting field unless accountants realize how the data is to serve the user of the information. This author believes too that the accountant must present the information as it relates to the decision to be made by a user.

Consider the following example. A decision-maker who is thinking about selling an old machine asks his accountant to present him with the relevant data. The accountant from the historical records indicates the book value of the item, the salvage value, and the method of depreciation; from a brochure he indicates the retail price of the new item. Evaluating the above, it is evident that the information is not suited to the decision-maker's needs. Better information might include estimates as to what the old machine could do in the future, what repairs it might need, etc. What is needed is to put forth the information with the decision as the focal point.

Horngren notes this change in emphasis when he says the following:

> The focus is on the relationship of accounting information to user needs. Because the user invariably utilizes the information for making a decision, the decision process becomes the starting point for analysis.[10]

In the same article, there is mention of this new role for the accountant and his accounting system:

> A particular accounting system produces information to a decision maker, who may use the information in choosing an action. The accountant must predict the relationships between the information system, the decision maker's prediction and action choice process, and the events that will occur.[11]

A final contribution of this study will be the continuance of this philosophy expressed by Horngren and other leading accountants. Just mentioning whether a deviation exists is not enough. More important is the decision as to whether something should be done about the deviation. This shall be the focus of this research.

FOOTNOTES

1. G.H. Hofstede, *The Game of Budget Control*, Assen, Netherlands Royal Gorcum, Ltd., 1967, pp. 8-11.

2. Henri Fayol, *General and Industrial Management*, New York: Pitman Publishing Corporation, 1949, p. 107.

3. Since the terms deviation and variance are often confused, this study shall designate a deviation as an amount different than the established standard. A variance shall be a measure of dispersion in a statistical sense.

4. Harold Koontz and Cyril O'Donnell, *Principles of Management*, McGraw-Hill Book Company, Inc., 1968, pp. 582-583.

5. *Ibid.*, pp. 588-591.

6. The figures in Table 1 were acquired from the accounting records at the company being investigated. Since this plant receives the raw materials at the standard price, for the plant there is no price deviation. Therefore, standard price (for materials) equals actual price.

7. The figures from Table 2 were acquired from the accounting records at the company being investigated.

8. The figures in Table 3 were acquired from the accounting records at the company being investigated.

9. Charles Horngren, "The Accounting Discipline in 1999," *The Accounting Review*, January, 1971, p. 4.

10. *Ibid.*, p. 5.

11. *Ibid.*, p. 5.

CHAPTER II

HISTORICAL OVERVIEW

2.1 Introduction

Before discussing the nature of the control process, it would be advantageous to present a brief historical overview of its development from the period some two thousand years ago to present day operations. The intent is simply to demonstrate how the events of the past have suggested an importance for each component to the control process. As these items are discussed, the interrelationships of the items shall be noted with the ultimate result being a description of the model representing the control process.

2.2 Control based on Areas of Responsibility

Interestingly enough, accounting control can be traced way back to the time of Alexander the Great around 256 B.C. The case in point is an estate where control was concentrated on assets, receivables, produce, merchandise, and raw materials. Each section of the estate, the farms, vineyards, herds of livestock, grain stores, household units, and administrative offices were managed by a supervisor who had to report daily or at least at frequent intervals on such items as performance and expenditures.[1]

What makes the case significant is that it introduces in a rudimentary way a major area of cost control, control by responsibility areas. Since the superior had the authority over these certain areas, he was responsible for the performance therein. Although control of this estate did not extend to profitability, there was still concern with operational efficiency. All expenditures were closely supervised, and any dishonesty was promptly reprimanded.[2]

2.3 Control over Manufacturing Operations

In the period from 1400 to 1600 additional cost techniques and practices had their origin. Their purpose was to (1) establish accounting control over the steps of production and (2) curb waste in the use of materials and labor.[3] Garner[4] points out that these instances of control were not adopted by only small industrial firms of that time but also the large business units which employed these practices as forerunners of the tremendous changes which would come almost 200 years later.

2.4 Detailed Cost Records

Any real progress in the development of cost control occurred after the Industrial Revolution.[5] One writer during the latter part of the eighteenth century, Robert Hamilton (Tradesmen's Accounts and A Book of Wages),[6] proposed that cost data should be recorded in more detail, that department records be kept to determine gains and losses on each activity, and also that comparisons between the cost of wages and related selling price, which was valuable information for control purposes, be kept.

Others from that period suggested more. Chester Babbage[7] (early 1800's) urged people to keep track of and analyze manufacturing costs. Arthur Gibson[8] (late 1800's) introduced control as a function of management and pointed out the need for separating costs in order that they be analyzed and made controllable.

2.5 Analysis of Data

In 1891 there appeared an article by John Mann[9] ("Notes on Cost Records: A Neglected Branch of Accountancy") which was significant because it presented two new ideas relating to the purpose of keeping costs records. First, it argued for an examination and explanation of past results. Secondly, it wanted management to use this information as a basis for forming a guide for future trading. Emphasis was being placed on discovering deviations from the estimates and correcting these deviations. Also, reliance on past results was used to reevaluate the standards for the next period.

2.6 Synthesization of Past Research

Research done on the control process during the last decade of the nineteenth century was more of a synthesization of what had been done previously. To achieve effective control, writers saw that:

1. Cost records should be kept not only for each job but also for each part or process entering into the complete job (Garcke and Fells, Factory Accounts).[10]
2. Statements should be issued more often than once a year (Plumpton, Manufacturing Costs).[11]
3. Current actual costs should be compared with estimated figures and the deviations noted (Plumpton, Manufacturing Costs as Applied to Engineering).[12]

All these examples were a beginning. They introduced careful records, standards, evaluation of discrepancies, and guides for the future. To control operations, business had to undergo a process of (1) making plans; (2) tabulating actual results; (3) comparing the actual with the plan; (4) correcting the deviations, if possible; and (5) starting again with a new plan for the following period.

2.7 The Planning Process

At the beginning of the twentieth century, two additional influences were present, factors which were to focus on the first aspect of control, establishing plans for the future. The first such influence, F.W. Taylor's[12] "Scientific Management," was concerned with the estimate of work performance for an individual task. These estimates, known as standards, were to be based upon systematic observation, measurement, and controlled experiment, all factors which meant a marked increase in reliability. They were recorded and made generally available within the company.

Early standards were engineering or physical standards expressed in the method of operation, either units of material or hours of labor.[14] What was really significant was that for the first time analytical tools were used to make the estimates, to establish the standards. It cannot be overemphasized that any credibility in a discovered deviation from standard depends on the credibility of the standard. Here was a first attempt to carefully prepare the standard.

Just as there was need for making plans in terms of individual performance, business was also interested in making estimates in a broader sense, namely for its entire operation. Emphasis on this plan of the future, known as the budget, also began to blossom at the beginning of the twentieth century.[15]

The development of budgets from this period on was fashioned after the government's use of such an instrument to achieve control. First, budgets were used by government as instruments of control over administrative officers, i.e., they placed limitations on their authority to spend (a limitation control).[16] Secondly, budgets were also used as guidelines for departmental expenditures (restraint control). With fairly elaborate records being kept, budgets acted as a basis for clerical control. Finally, they were used to achieve communicative control where interim reports were prepared and distributed to department heads.[17]

As with these government purposes, business controls, too, were facilitated by the use of budgets. Where actual results differed significantly from the budgets, demands were made for an explanation.

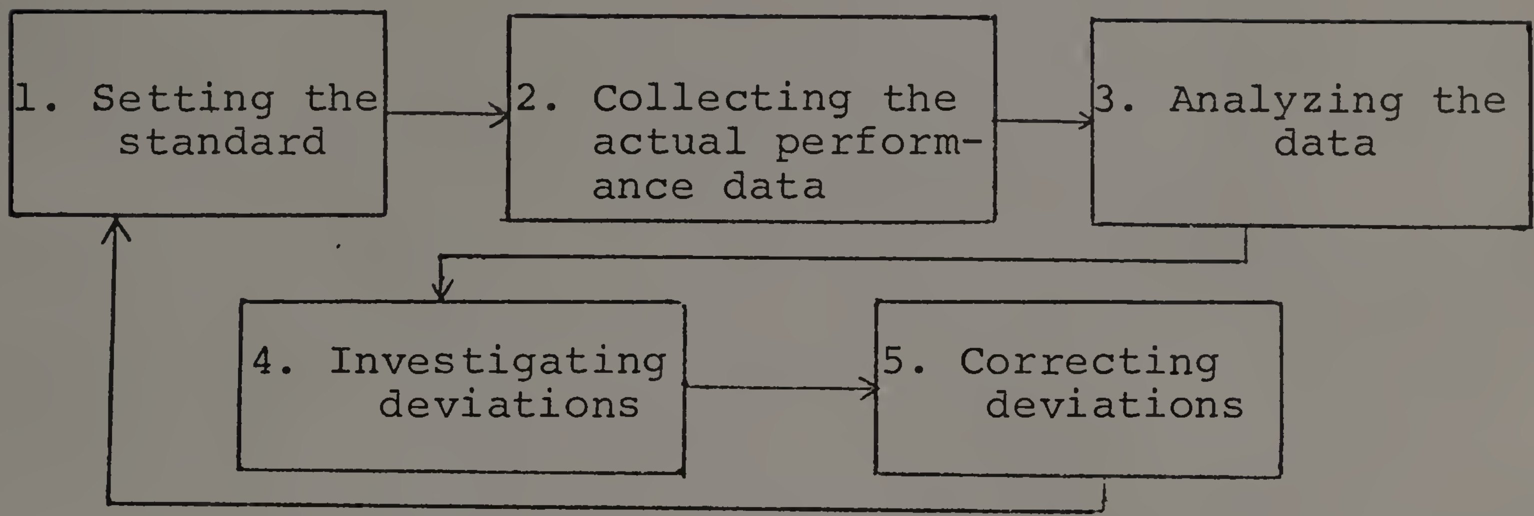
2.8. The Control Process

As time passed, control over the entire operation and its individual components developed. Large-scale applications were used in the United States in the depression years after 1930. Surveys have indicated that while only 51% of the well-established companies were using budgets in 1941, 95% were utilizing such an instrument in 1958. Now, almost all do.[18]

What has evolved is a control process which seeks to insure that future operations will match what is planned by management. In the following figure, a visualization of this control process with the interrelationships of the various components can be seen:

Figure 1

Components of the Control Process



1. Setting the standard--this is the process by which the future plan of action desired by management is formulated.

2. Collecting the actual performance data--this is the process by which actual performance is recorded and arranged according to particular responsibility areas.

3. Analyzing the data--this is the process by which various aspects of the actual data is compared to the standards.

4. Investigating deviations--this is the process where the supervisor in charge (perhaps with the plant manager) decides whether to investigate a deviation from standard.

5. Correcting deviations--once the problem area is known, this is the process by which the supervisor decides what to do with the problem.

2.9 Summary

Each of the items mentioned in this chapter serve as building blocks to the control process as depicted in Figure 1. As time passed, the foundations of a system by which management could seek to control its operations were being built.

In the several centuries B.C., control meant the splitting up of various segments of the operation into responsibility areas where some form of operational efficiency was desired. Years later (1400-1600) control was applied to the manufacturing operation such that the elements of cost, material, labor, and overhead, were carefully considered. After the Industrial Revolution, detailed cost records were being kept so as to collect actual results of performance. At the end of the nineteenth century, attention was directed to analyzing the deviations from standard and then correcting them, if possible. When the twentieth century began, the standards themselves were analyzed so that by 1972 an effective control system could be designed.

In the next three chapters, attention shall be directed to a careful examination of each of the five components of this control process (Figure 1). Having done this, the stage will be set to examine the suggested investigation tool, noting how it can assist in achieving effective control.

FOOTNOTES

1. H.P. Hain, "Accounting Control in the Zenon Papyri," The Accounting Review, October, 1966, p. 701.

2. Ibid., p. 701.

3. S. Paul Garner, "Historical Development of Cost Accounting," The Accounting Review, October, 1947, pp. 386-387.

4. Ibid., p. 387.

5. Paul Crossman, "The Genesis of Cost Control," The Accounting Review, October, 1953, p. 522.

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CHAPTER III

SETTING OF THE STANDARD

3.1 Introduction

The first aspect of the control process is the setting of goals and plans which are desired for the upcoming period of operations. Designated as budgets and standards, these plans set for the entire organization what is to be expected in the future. Through the control system, those with responsibility seek to match the actual performance with these plans.

In this chapter, a careful examination shall be made into: (1) the concept of standards and budgets, (2) the tightness and looseness of standards, (3) ways in which standards are calculated, and (4) a way to gain the acceptability of the standards.

3.2 Notion of Standards and Budgets

Since the concern of this study is restricted to a manufacturing process, it is first necessary to identify what types of plans are set within this operation and in turn how the manufacturing costs are related to these plans. Therefore, this discussion shall concentrate on: (1) the overall plan (the budget), (2) the plan related to the specific unit (the standard), and (3) the relationship of the production costs to these budgets and standards.

3.2.1 Budgets

One begins with budgets, since they represent the overall financial plan. Eric Kohler[1] defines a budget as the financial plan which works as a pattern for and a control over future operations. They work as a systematic plan for the utilization of manpower, material, or other resources. For a budget to prove effective, it must have both aspects of the management function: planning and control.

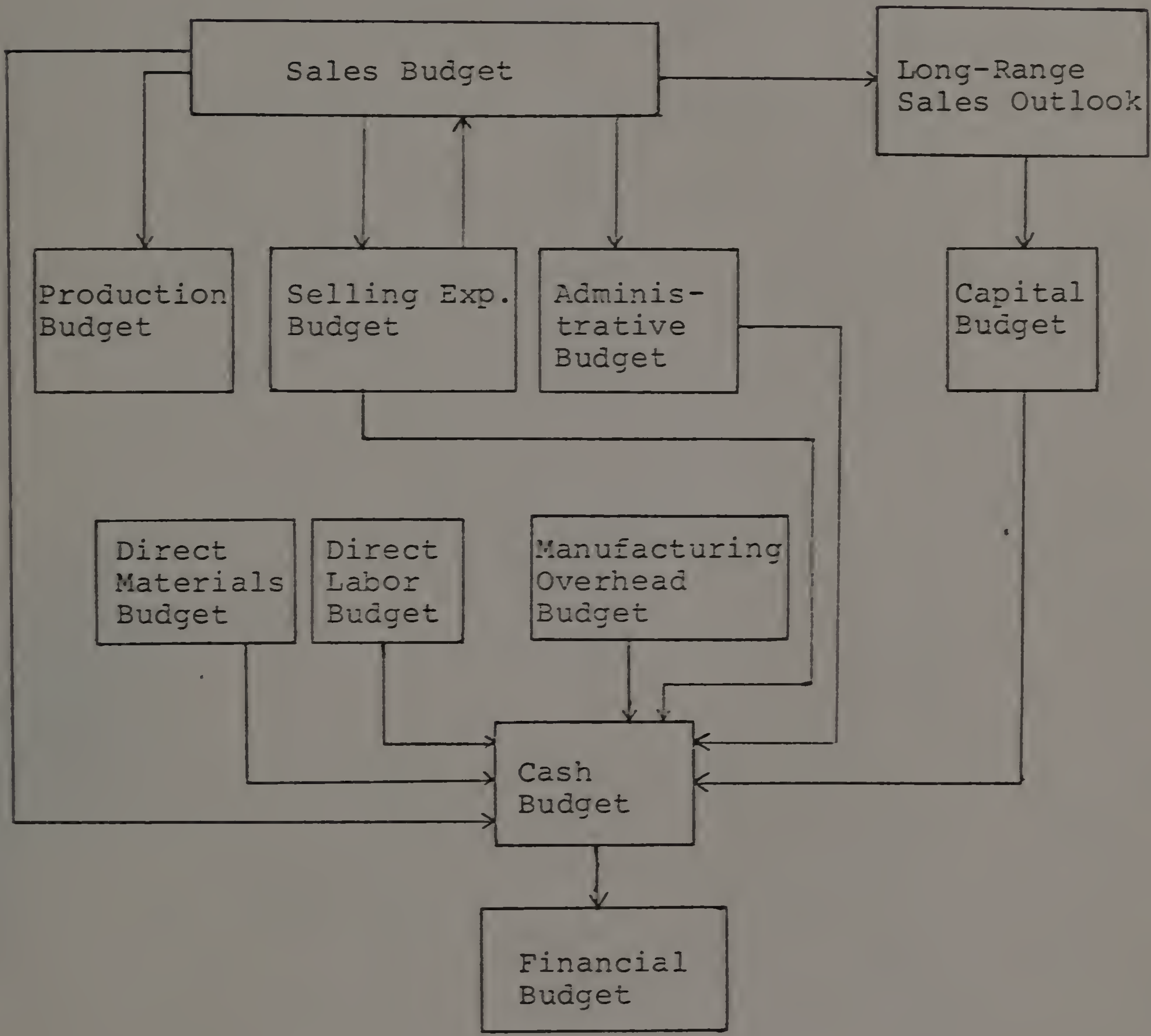
In terms of planning, G.H. Hofstede[2] points out an interesting distinction between a budget which forecasts and one which plans. If a budget forecasts, it merely estimates beforehand. However, if it plans it is arranging beforehand. A plan is a more active state where management is constantly striving for a particular goal, in this case the budgeted amount. By planning, there is a continual attempt to shape the future by coordinating the resources. One function, therefore, of a budget, is to plan.

To control operations, management must take the budgeted figure and compare it with the actual results. A. Stedry[3] notes that the difference itself is not a control, for costs are not controlled by compiling statistics about them. The control consists of the steps that management takes to regulate or limit the costs. The effectiveness of these steps is gauged by the degree to which actual figures approach the budgeted ones.

Types of budgets are numerous. Figure 2 gives a picture of a manufacturing firm with the several budgets it would de-

Figure 2

Master Budget for a Hypothetical XYZ Co.[4]



termine at the onset of an accounting period for its operations. The entire accumulation of individual budgets is known as a master budget which in turn is used to prepare an estimated income statement and balance sheet for the coming period.

Notice how many budgets are functions of other budgets. For example, in order to know one's production requirements, the sales budget must be determined. In order to prepare a financial budget, all the others must be computed. By coordinating efforts, by avoiding waste, and by improving management decisions, there must come higher profitability. By having advance knowledge of the cash needs, there is a better chance for an optimal liquidity position.[5]

3.2.2 Standards

If budgets represent a plan and means of control over future operations on a large scale, then a standard represents the same but on a smaller scale.[6] If all costs were split up department-wise, then the estimated cost would be a budgeted cost. If the costs were split up product-wise, that is, on a unit basis according to the three elements of cost (direct material, direct labor, and overhead), then the cost would become a standard cost.[7]

In the historical overview, it was shown that budgets and standards developed at about the same time (beginning of the twentieth century), but in the earlier years their development was largely separate.[8] Standards developed in the factory (F.W. Taylor's "Scientific Management") while budgeting was applied first to the financial aspect of the business. Later, it was realized that both were merely applications of the same management philosophy. Indeed, they were complementary parts of a complete program of cost control.[9]

At the time of the scientific management influence, the term standard was more than a planned estimate of the future. Morris Cooke[10] (Cost and Production Handbook) points out that the standard was a carefully thought out method of performing a function. What resulted was a statement by management that the standard was simply the best method that could be devised at the time it was drawn. What is interesting is that the standard originally signified a "maximum" production requirement. If, for example, the direct labor standard were one hour to produce ten units of product, then this standard would be the most efficient way to produce the ten units. Today, because of many other influences (to be discussed later), standards may not in the short-run reflect the most efficient performance. Instead, in the interest of long-term benefits, the objective may be to implement a standard at less than the maximum performance level.

In distinguishing between standard and standard cost, one finds that the two are so related that one is generally included with the other in any description of cost or profit control mechanisms.[11] Stedry[12] points out that the choice of physical units or dollars is really arbitrary, and hence the two terms can be used more or less interchangeably (Author agrees).

3.2.3 Relationship of Production costs to Standards and Budgets

Since this study is concerned with a manufacturing operation, the next step is to relate the various manufacturing items to standards and budgets. Specifically, then, for what items will standards be expressed? Generally, there will be standards for those production costs which vary with the number of units produced (variable costs) and budgets for the others:

A. Direct Materials (variable)

The cost of materials is often a substantial part of the total product cost. A standard price is set for each class of material to be purchased. If the purchasing function is carried out properly, the standard price should be attainable. In addition, usage standards are established for production. They are usually expressed as "it should take two units of raw materials to make one whole unit of product."[13]

B. Direct Labor (variable)

Like materials, labor must be controlled on a price and quantity basis. Production standards for labor state how many units (parts, assemblies, etc.) should be produced per time period (either minute, hour, day) or expressed another way may indicate how much time is allowed to produce one whole unit of product. Whether standards are expressed in terms of performance per unit of time or time requirement per unit of work is quite irrelevant.[14]

It should be noted that usually direct labor refers only to the principle task at hand. All other tasks related to the principle activity (indirect items such as sick leave, facation time, etc.) are considered factory overhead.

C. Overhead (variable portion)

Like the labor cost element, that portion of the overhead cost which varies in amount with the production has standards for price and quantity. Items such as polishing supplies and lubricants have both an expected unit cost and an expected usage requirement. Most often, the usage requirement is expressed as some function of direct labor, since the variable overhead amount will increase as the number of labor hours increase (labor hours could be expressed as man-hours or machine-hours).

D. Overhead (fixed portion)

The fixed overhead is presented as a budgeted figure and is usually controlled in the planning process as care is taken at the start of the accounting period to estimate in total what the period costs should be.

3.3 Tightness and Looseness of Standards

For each of the above types of cost (except fixed costs), the budget committee establishes standards (for both price and quantity). Since this research study shall work with a particular labor usage standard, the following discussion shall relate to the setting of this type of usage standard.

In fixing a figure to this plan for the future, management must decide to what extent the standard will be a representation of the ideal situation. Based on a particular strategy to achieve optimum output from the subordinates, the following types of standard may be used:

A. Tight standards

This type of standard represents the theoretical, ideal, or perfection standard. The designated amount indicates the best performance possible given the equipment in the plant. Allowances are made possibly for rest periods but not for waste, spoilage, or lost time. For this type of standard, deviations are probable.[16]

B. Attainable good performance standards

This type of standard can be met or even bettered, but only by what is regarded as efficient performance. Deviations on both sides of the standard are possible.

C. Loose standards

In this case, the average past performance is used to determine the standard. No adjustment is made for past wastes and inefficiencies. Since jobs on which performance was poor are likely to be more numerous and more extreme than jobs on which performance is particularly good, this standard is considerably looser than the other two. Unfavorable deviations (actual time being more than standard time) will have to be carefully studied.[19]

Whichever type of standard is selected, either tight or loose, will depend upon management's philosophy as to which standard will achieve more effective control. Incorrect time standards may lead to many deteriorating consequences. Langier[17] points out that an exaggerated tightness of the standard may bring about a feeling of bitterness and growing dissatisfaction among the operators which could indirectly cause decreased production. If the standards are too loose, they may contribute to lower productivity since the minimum set by the standard is not met. Many times loose standards are utilized as a compensation of deficits arising from the fact that other standards have been too tight. When this occurs, there appears a lack of sincerity and a mutual distrust between management and labor.

In a comprehensive field experiment by Stedry and Kay,[18] carried out among the foremen in a department of a large engineering plant, the following was discovered: (1) higher productivity was achieved with a more difficult standard, but (2) difficult standards must be used carefully; a mechanism must be built in to revise the standard if the individual sees it as impossible, or otherwise it will have a long-term adverse effect on performance.

The conclusion was that standards must not make too many allowances. With loose standards, the effect is poor motivation, the motivating effect becoming stronger only when the standard becomes tighter. Over a certain limit of tightness, though, motivation is poor again. To generalize about this limit, one must be careful, since the limit depends on various factors in the situation, in management, and in the personalities of the subordinates.

3.4 Techniques to Calculate the Standard

In determing a labor usage standard, the particular analyst begins by estimating a "normal time,"[20] defined as the average time for performance using average skill and average effort.[21] It is the calculation of a performance level which makes no allowance for waste, machine breakdown, etc. (a tight standard). Once this figure is determined, the budget committee can discount it to any level it desires (if it seeks an attainable or loose standard) to allow for waste, machine breakdown, etc.

It should be mentioned that the labor usage standard given to the workers is usually expressed in physical units (minutes, hours, tons, pounds, etc.). Later, when the supervisor and plant manager wish to analyze the data, they may convert the physical standards to dollar standards. In this way, the individuals are responsible for meeting costs of the operation (see Chapter IV).

To calculate this normal time, the following techniques can be used: (1) performance rating, (2) stop-watch technique,

(3) work sampling, and (4) standrad data work measurement systems (MTM).[22]

A. Performance Rating

Requiring considerable experience, the analyst determining the standard must first select a pace or performance level as standard. Observing this pace and comparing it with various other paces, the analyst learns to judge an average performance level in percent of the standard pace. If, for example, actual worker performance was .6 minutes per operation and the rating was 125 percent of normal (determined subjectively by the experienced analyst), normal time would be .75 minutes:

Normal time = Actual observed time x Performance rating (expressed as decimal)[23]

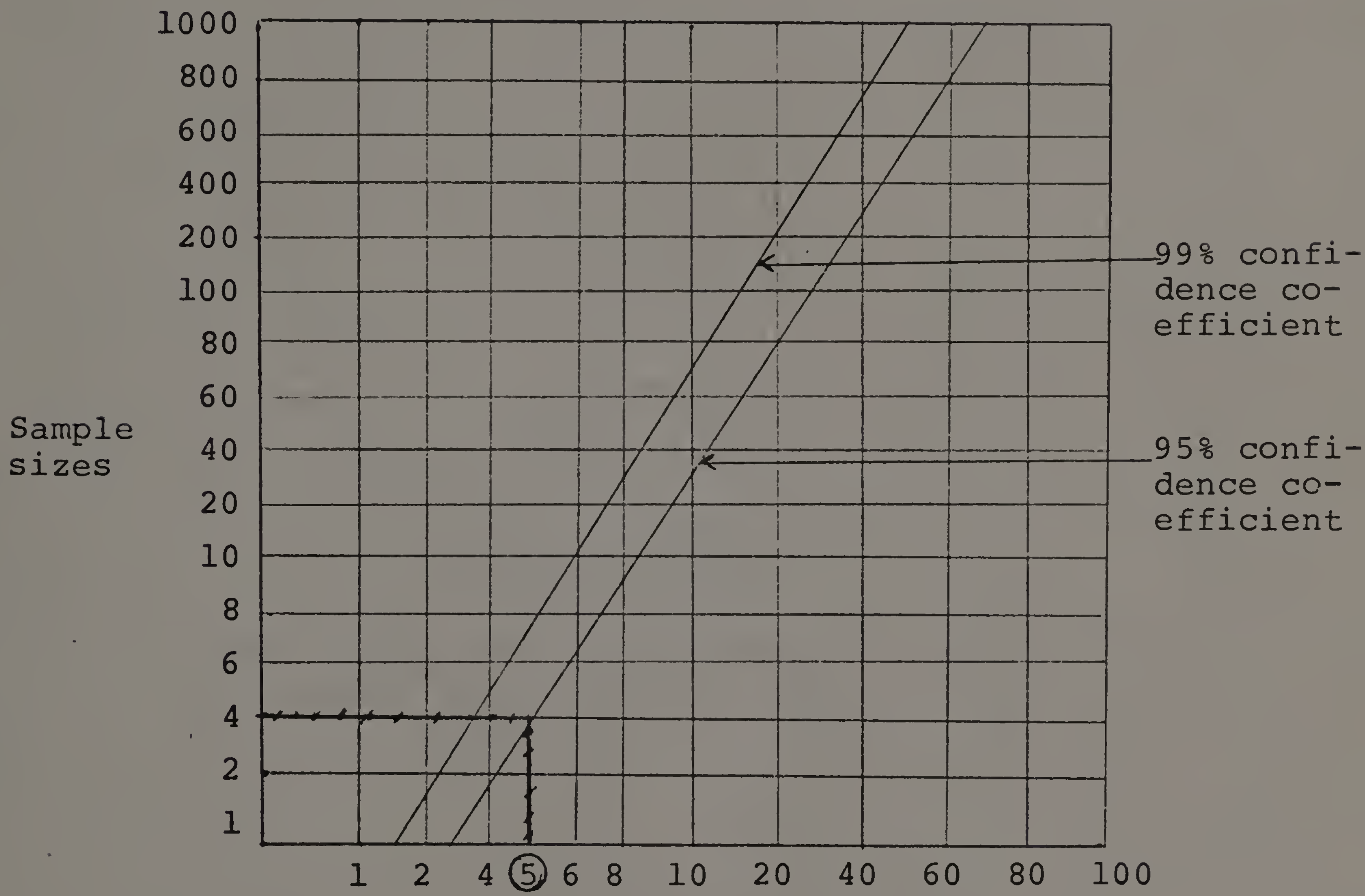
B. Stop-watch technique

With this technique, the analyst uses a sample study of an experienced and trained operator to calculate normal time. After the method of operation has been standardized and the operator selected, a number of observations is taken pertaining to the selected operator and the actual times required for performance are recorded. Next, calculations on the sample (obtaining the mean and standard deviation) are made to determine normal time.

As the analyst may desire a certain precision level for his estimate, he would then calculate the necessary sample size to obtain this precision. To illustrate this point, consider figure 3 which is a chart for estimating the sample size required to obtain maximum confidence intervals:

Figure 3

Determination of Required Sample Sizes with Stop-Watch Technique[24]



Coefficient of variation (percentages)

If the precision desired is 95%, that is, the analyst wants the mean of the sample to be within a given percent of the true mean 95% of the time, and that given percent around the true mean is 5 percent, then the required sample size is "4".

C. Work sampling

First introduced to industry by L.H.C. Tippet[25] in 1934, work sampling is the process by which the analyst makes a large number of random observations determining whether the operator is working or idling. The percentage of the tallies that are recorded "working" as opposed to "idle" are estimates of the actual percent of time that the operator was working and idle. To obtain normal time, the following calculation would be made:[26]

Normal time = (T x W x A)/P

where T = total time of the study in minutes
W = work time expressed as a decimal of the total time
A = average performance rating expressed as a decimal (the performance rating was determined by the experienced analyst--see performance rating method of calculating standards)
P = total number of pieces produced

It is interesting to note that studies have shown that the two techniques, stop-watch and work sampling, produce similar results. The difference appears to be in their field of application and the behavioral implications of the two techniques on the operator.[27]

D. Standard Data Work Measurement (MTM)

Time value systems, such as Methods-Time-Measurement, depend upon the calculation of the time requirement for each minute segment of an operation. The analyst lists each motion employed (moving, grasping, turning, releasing, etc.) and records a designated time for each. Performance ratings are used to develop the time values for each segment, and therefore, the normal time is merely the accumulation of the times for each segment.[28] It should be pointed out that often times methods such as MTM are used in conjunction with one of the other techniques since some measurement of the entire task is desired.[29]

It has already been shown that organizations will employ a type of standard somewhere between the normal time (a tight standard) and another time which makes allowances for such factors as: (1) personal time, (2) measured delays normal to the job, and (3) fatigue. To quantify these items, use of the stop-watch technique and especially work sampling can help provide measurements. Usually, an organization will designate some percentage as the amount allotted for various allowances. Therefore, if the allowance percentage is 5 percent, then the minutes of personal time in a normal 8-hour day will be 24 minutes (.05 x 480). If the normal time has been measured as 1.0 minute per piece, then the standard becomes:

$$\begin{aligned} \text{Standard} &= \text{Normal time} \times 100/(100 - \text{percentage allowance}) \\ &= 1.0 \times 100/\ 9.5 \\ &= 1.053 \text{ minutes per piece} \end{aligned}$$ [30]

Since many labor tasks are highly procedural and relatively simple, learning curve theory need not be explicitly considered or included in the model.[31] However, if the task were a complex one or one requiring highly proficient manual dexterity, learning curve theory should be incorporated.

Briefly, the inclusion of learning curve considerations into the model would involve the use of regression analysis on successive samples to establish the slope and intercept of the trend line (comparing units produced per hour versus number of days, for example). Further analysis would be required to determine whether the variance is also changing as increased operator skills result in greater consistency.[32]

3.5 The Attainment of Acceptability for the Standard

Although behavioral considerations are very much a part of the entire control system, it is beyond the scope of this research to consider the entire field. Therefore, attention shall be directed only to the behavioral considerations which affect the direct implementation of the proposed management tool.

Any success in the use of a control technique whether simple or complex depends upon the acceptability by the subordinates. In gaining this acceptance, the crucial point seems to be at the standard itself. If the standard is not accepted, then it will be difficult to insure an effective control system. Based on the evidence in the literature, some level of participation in the standard-setting can assure this acceptability.

3.5.1 Relationship of Management to the Subordinate

To give a full explanation as to how the standard can be accepted, it would be beneficial to discuss the way in which management and subordinate are perceived by each other. In this way, it will be possible to see what can happen if management has the wrong attitude toward its subordinates.

3.5.2 A Simplistic Impression of Human Nature

At the time of F.W. Taylor's scientific management movement,[33] there was a mechanistic, materialistic view of human behavior. It was believed that the production worker had an inherent dislike for work and would avoid it unless there was economic incentive. D. McGregor[34] points out (in his Theory x) that the control process had to coerce, direct, and even threaten the workers with punishment to get them to put forth an adequate effort.

In addition to this pessimistic picture of human nature, it was believed that there was a best way of behaving that could be thought out by specialists, learned by individuals, and maintained by appropriate incentives. The burden for such a program would be felt primarily at the top with these men using authority as the central, indispensible means of management control.[35]

With such beliefs the standard would be the mechanism which would indicate the best way to perform. It would also instruct the worker as to the expected level of performance.

If he performed at this level, he would receive his economic reward (his pay). Very importantly, since the belief about the subordinates was of one desiring to be directed, it would be the responsibility of the technical staff of the plant such as the industrial engineers and design engineers to establish the standards. Any participation in the control process by those being controlled would not be advantageous.

Besides the scientific management influence, traditional behavioral theory about the production worker was derived primarily from the study of the military and the Catholic Church.[36] Today, there is some question as to the reasonableness of the derived assumptions. For example, unity of command (where one worker has one boss) may be appropriate on the battlefield or even in some organizations, yet it is not a universal principle. Political, social, and economic factors may also influence organization members and management practice. Finally and most importantly, many of the underlying scientific management principles about human behavior may be at best only partially true.[37]

3.5.3 A More Complex Attitude

One of the first instances that drew attention to the erroneous, simplistic assumptions about the individual were the Hawthorne studies which dramatically showed that in determining work patterns the need to be accepted and liked by one's fellow workers was as important as the economic incentives offered by management. The manager, to use an appropriate strategy, would have to acknowledge the existence of needs other than purely economic ones.

Any discussion of the multiplicity of human needs must include Maslow's hierarchy for it points out the appearance of new needs once old ones are satisfied.[38] Briefly, a human being will begin with physiological needs which must be satisfied first before the next need, safety need, will be met. As safety needs are satisfied, affiliation needs appear. They are replaced with the esteem need which when met is replaced by the highest need, that of self-actualization. With a work force consisting of many individuals, each with different needs, it is quite unrealistic to characterize "the worker" with only one description.

In the works of C. Barnard,[39] the individual is thought of as more complex. Barnard defines the individual as "a single, unique, independent, isolated, whole thing, embodying innumerable forces and materials past and present which are physical, biological, and social factors." The behavior of individuals, then, is a result of psychological influences combining all these factors. To achieve effective control, management has to reconcile the conflicting forces that may arise, the instincts, interests, conditions, positions, and ideals of the individual.

Further proof of the changing attitude towards worker behavior is the Theory Y approach of McGregor.[40] Here, the expenditure of physical and mental effort in work is as natural as play or rest. With this as a guiding principle, man will thus exercise self-direction and self-control in the service of objectives to which he is committed. The conclusion is that the standard can achieve control if the individual is committed to it.

3.5.4 Unanticipated Results

Each of the above, McGregor, Maslow, and Barnard, have demonstrated the dynamic aspect of the individual. The implication is that in the formation of the standard (as the objective of what is intended for the worker) the subordinate must have some role. Studies have shown that when the control process does not reflect this point, unanticipated results may occur.

In 1931 the National Conference Board in New York[41] in its statement on Budgeting Control in Manufacturing Industries said the following:

> By 1930 it was recognized in business circles that imposed budgets resulted in some dissatisfaction and advice was given to prepare them in the departments and have them revised or edited in the central offices.

What is significant is not that management was aware that workers might be dissatisfied, but instead that it would be to management's advantage to eliminate this dissatisfaction.

Twenty years later, Chris Argyris[42] in a comprehensive study conducted open-end interviews of line and staff supervisors in four middle-sized manufacturing organizations. The key unanticipated output of the budget control process appeared to be a pressure which was exerted from the system to the individuals in the organization.

One consequence of this pressure was that employees tended to unite against management and tended to place the factory supervisor under tension which could all lead to inefficiency, aggression, and perhaps a complete nervous breakdown on the part of the supervisor.[43] Consider the following example. If certain allowances were added to normal time to arrive at the standard and pressure caused management to eliminate a portion of the allowances (tighten the standard), the workers would group together trying harder to keep production at this new level and prevent it from rising again. Once the group had formed, it would be difficult to break.[44]

This pressure can have even more impact on the individual since the employees, feeling dependent on management, may perceive the controls as instruments of punishment, coercive mechanisms intended only to increase constantly and unilaterally the production goals. As a result, the controls accent the failures without showing why such failures may be necessary.[45]

With regard to the supervisor, pressure prohibits him from joining a group against management (as the workers have done), since he is partially identified with management and also seeking to advance with management. Pressure can intensify between individuals and supervisors to the extent that they are working more against each other than together.

If even a portion of these unanticipated results occur and if man is more complex than was initially described, the setting of standards merely by the engineer will not gain the acceptance of the subordinates. For the control process to be effective, the standard must motivate the worker to perform at that level. In the formation of the control mechanism, the subordinate must play some part. Participation is needed!

3.5.5 Participation in the Standard-setting

Participation can be defined as the process of joint decision-making by two or more parties in which the decisions have future effects on those making them.[46] Management can allow participation on three levels: (1) decisions on the structure of the system, (2) decisions on setting the standards, and (3) decisions about action on the reported deviations from standard. Based on the evidence in the literature, it will become clear that participation at least on the second level is necessary for effective control.

It should be pointed out that standard-setting participation by subordinates can also take place on three levels:

(1) decisions left entirely to the subordinate, (2) decisions taken by superior after hearing the subordinate, and (3) decisions taken by superior and then explained (through answering questions) to subordinate.[47] Whichever level of decision-making is used will depend upon the nature of the subordinate and the nature of the particular situation. The final decision as to which level will be employed, will rest with management's beliefs as to the net advantage of each.

Evidence in the literature suggests that some form of participation in the standard-setting will bring better control. Below are some of the reasons:

A. Overall concern for the control function

Since more individuals are a part of this function, there will be more of a widespread responsibility for review and control. At times, lower units will impose more rigorous reviews and tighter controls than top management. They will believe that since they were given the opportunity to participate, they should accept the responsibility to evaluate themselves fairly.[48]

B. Better communications

Management has traditionally focused most of its attention on downward communications, not upward. As a result, with the mounting pressure exerted by management on employees, not only have the employees been reluctant to voice their complaints to their superiors, but they also have found it more difficult to communicate their ideas for improving conditions. Feelings of mistrust develop. Serious discrepancies exist between what the foremen think is reasonable production and how the workers feel about it.

With better communications, interaction is with individuals and group; the flow is up, down, and with peers. It is initiated at all levels.[49] In addition, the feedback cycle between superior and subordinate is closed. The result is that the organization becomes adaptable to change and is guaranteed a higher quality of decisions.[50]

C. Increased motivation

For participation to motivate the subordinate, it must also fulfill his needs. One piece of work by March and Simon and another by Herzberg et al. provide evidence that participation can fulfill the need for autonomy.[51] Patchen[52] hypothesizes that participation can lead to an identification with the organization (affiliation need) which makes the individual more susceptible to the organization influencing him. In terms of the need for achievement, Patchen (in the same article) notes that participation may help the individual to get a sense of personal achievement from reaching goals in his work. To fulfill the need for self-actualization, C. Argyris[53] speaks of a participative leadership which emerges for the subordinate who helps in setting the standard.

D. Higher Morale (Study by Bass and Leavitt).[54]

E. More Favorable Attitude Towards Appraisal System (Study by Meyer, Kay, and French).[55]

F. Blending Together of Informal and Formal Organization

All social forces now support each other in order to achieve the organization's goal (the standard).

G. More Complete and Accurate Information

Since the subordinate will be guiding his own behavior and that of the related work group by the standard he helps set, there is strong pressure to obtain complete and accurate information. As a result, the information and measurements tend to be more complete and accurate.[56]

H. Better Understnadinf of Standards

This is simply due to including the subordinate in the informational process.

I. Higher Productivity

Any additional mechanism used in the control process must ultimately assist in the added productivity of the workers. If participation will give the above results or even move towards these goals, then it is expected that productivity would increase. In the study by Bass and Leavitt it was found that participation did yield higher productivity. Meyer, Kay, and French had similar findings.[57]

3.5.6 Determination of the Ideal Level of Participation

Most of the literature does suggest some need for participation in the standard-setting. What is lacking in the literature is evidence as to which level of participation is most effective. Also, there is little discussion as to whether only the supervisor should participate with the engineer or whether the production workers should too. To answer this last question the following characteristics must be considered:

A. Personality traits of the participants

Vroom[58] notes that authoritarians and persons with weak independence needs are apparently unaffected by the opportunity to participate. The reverse is also true.

B. Personality traits of the superior (French, Kay, and Meyer).[59]

C. Cultural influences on the participant

Coch and French[60] showed the effect of group participation in a U.S. Pajama factory (favorable). However, in a study by French, Isreal, and Aas with Norwegian workers, there was a stronger tradition to unionize and not desire participation.

D. The situation

Leavitt[61] discovered that the degree to which the task was mechanized or routinized determined the level of necessary participation. In terms of a routine task in the factory, the need was of course less. Also, the amount of participation that the subordinate had utilized before would influence the need for participation at this time. The more participation one enjoyed before, the more would be desirable now.

3.5.6 Summary

Much attention has been given to the behavioral aspects of setting the standard, since the standard is the first element of the control process and the crucial item which must be accepted. While it was earlier believed that man's nature could be described quite simply (mechanistic, materialistic, lazy, etc.), the literature has pointed out the change in view with man being considered more complex.

With this new description in mind, it has been shown that if the subordinate is not considered, unanticipated, harmful results can occur. To curb these problems as well as to gain an acceptance of the overall process, some level of participation is necessary. While the ideal level of participation is unknown, participation at least in the standard-setting is helpful.

3.6 General Summary

It is evident that both standards and budgets play a key role in the entire control process. Similar in many ways, these plans of action are set for each element of the organization so that each individual knows what is expected of him.

After discussing the relationship of standards to the entire control process, it was shown how management must establish standards for the three elements of cost (direct material, direct labor, and overhead) in terms of both price and usage. Whether management employs a strategy of using either tight or loose standards, it must actually compute the standard (expressed first in physical units). Therefore, the setting of the labor usage standard was illustrated by the use of various engineering techniques.

Finally, to give evidence as to how the standard would be accepted, it was shown that some level of participation in the setting of standards can be the necessary step to gain this acceptability.

FOOTNOTES

1. Andrew Stedry, Budget Control and Cost Behavior, Englewood Cliffs, New Jersey, 1960, p. 3.

2. G.H. Hofstede, The Game of Budget Control, Assen, Netherlands, Royal Van Gorcum, Ltd., 1967, p. 20.

3. Stedry, p. 10.

4. Budgets can be split among divisions, branches, departments, sub-budgets, etc. This is an illustration of a typical manufacturing operation. For a complete description of each particular budget see Moore and Jaedicke, Managerial Accounting, South-Western Publishing Co., Ohio, 1967, p. 465.

5. Hofstede, p. 22.

6. Stedry, p. 9.

7. Hofstede, p. 27.

8. N.A.A. Research Report 11-15, How Standard Costs Are Being Used Currently, 1948, p. 2.

9. Ibid., p. 3.

10. Ibid., p. 3.

11. Stedry, p. 5.

12. Ibid., p. 7.

13. Carl Moore and Robert Jaedicke, p. 377.

14. Elwood Buffa, Modern Production Management, John Wiley and Sons, Inc., New York, 1965, pp. 331-332.

15. Overhead costs are defined as those production costs other than direct material and direct labor.

16. N.A.A. Research Report 11-15, p. 8.

17. Franciszek Jan Langier, "Statistical Control of Time Standards," Management Science, 1963, 4, pp. 527-541.

18. A. Stedry and E. Kay, The Effects of Goal Difficulty on Performance, Publication BRS-19 by Behavioral Research Service, General Electric Company, Crotonville, N.Y., 1964.

19. N.A.A. Research Report 11-15, p. 8.

20. Buffa, p. 334.

21. Stedry, p. 10.

22. Buffa, p. 337; see, for example, G. Nadler, Motion and Time Study, McGraw-Hill Book Co., New York, 1955, pp. 439-445.

23. Ibid., p. 337.

24. Ibid., p. 342.

25. Ibid., p. 345.

26. Ibid., p. 349.

27. Ibid., p. 353; see, for example, R.M. Barnes and R.B. Andrews, "Performance Sampling in Work Measurement," Journal of Industrial Engineering, Vol. 6, No. 6, pp. 8-18.

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29. Ibid., p. 358.

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CHAPTER IV

COLLECTION AND ANALYSIS OF THE DATA

4.1 Introduction

If management is to control its operations, then it must assemble and analyze the actual performance data for the different segments of the operation. For the individual worker, it is extremely important that he understand that his performance is being checked (he would probably act differently if he thought there would be no checks). For the supervisor, there is the opportunity of learning how to obtain better performance in the future.[1]

For the above reasons, management desires to compare the actual performance data with the standard. As a first step, the data must be collected. Once this procedure has been carried out, the data must then be analyzed.

4.2 Collection of the Data

In order for the control process to prove effective, the reporting system must be designed around the responsibility centers of individual supervisors. In other words, the supervisor of an operation (for example, the heat-sealing of hair brushes) is the one held accountable for deviations from standard for items within that department for which he has control.

In manufacturing organizations, the various segments of the operation can be usually categorized into one of three responsibility centers: (1) cost centers, (2) profit centers, and (3) investment centers. If the supervisor in charge of a particular segment of the organization has control over only costs, then his department is considered a cost center. If he also directly influences the sales of the item, then his overall operation is considered a profit center, and he is measured accordingly. Finally, if he has control over the assets which go into manufacturing the item, then the operation is deemed an investment center.

What is important is that the responsibility for obtaining the standard should be fixed as near as possible to the point of action and also placed upon the individual who is charged with the responsibility of the operation and the related items.

It should be noted that in the application of the model on a particular labor operation (heat sealing of hair brushes), since the supervisor only influences the performance of the operators and not the sales of the item, the appropriate responsibility center to consider would be a cost center.

Before discussing the actual performance report, it should also be mentioned that the supervisor's responsibility need not be in terms of dollar figures. In other words, if the supervisor has no control over the workers' pay, it may be beneficial to express the standard (for a labor task) and the actual results in physical units. Therefore, the concern may be to meet so many units per hour, not so many dollars worth of goods.

The information as to actual performance is assembled in terms of the specific department according to time or job. Reports are given to the supervisor and simultaneously to the plant manager indicating how the actual data compares to the standard.

In assembling this information, the following must be kept in mind:[2]

A. Objectivity

It is very important that an independent worker such as a scheduling clerk record the actual performance for any particular worker. There must not be any conflict of interest in recording this information.

B. Timeliness

The reporting must occur so that deviations can be spotted before they are completely out of hand. If the supervisor wishes to control future operations, then he desires to handle problem areas as soon as possible. Of course, in determining how many checks shall be made on actual performance, management must compare the cost of a check with the estimated value of the information received (are the added checks causing a reduction in deviations?).

C. Clarity and Ease of Understanding

In the performance report, it is vital that the supervisor have at hand the following items: (1) the particular task being done (heat sealing, for example), (2) the individual working the task (Mrs. Jones), (3) the item being worked on (brush 400), (4) the standard for that task (300 units per hour), and (5) the actual performance (290 units complete). Although it seems that the presentation of this information is simple enough, often times the summary data is surrounded by numerous incidental figures, and key figures are omitted. The necessity for highlighting the important figures cannot be underestimated.

4.3 Analyzing the Data

Once the actual performance is known, it is then necessary to analyze the differences from standard. In setting the standard, it was shown that in terms of the manufacturing operation, standards are set for materials (price and quantity), labor (price and quantity), and overhead (the variable portion having a price and a quantity standard, and the fixed portion treated as a budgeted figure). Which deviation figure is placed with a particular supervisor is determined according to the items over which he has control.

To understand the nature of the various deviations, consider the following:[3]

A. Direct material deviations

Price--it is defined as the product of (1) the difference in unit price (standard minus actual) and (2) the actual quantity purchased. Ordinarily, the purchasing executive would be responsible for this deviation.

Figure 4

Material Price Report[4]
(Hypothetical)

Material Code No.	No. of units purchased	Standard price	Actual price	Deviation per unit	Total deviation
100	1000	$10	$9	$1	$1000

Quantity--it is defined as the product of (1) the difference between the material used and the quantity of material allowed for the number of units produced and (2) the standard price. The supervisor within whose department the raw materials are used would be responsible for any deviation.

Figure 5

Material Consumption Report[5]
(Hypothetical)

Material Code No.	No. of units used	Standard no. of units	Quantity deviation (in units)	Standard price	Total deviation
100	400	325	75	$10	$750

B. Direct labor deviations

Rate--it is defined as the product of (1) the difference in wage pay (standard minus actual) and (2) the actual labor hours consumed. Often times, because of a union, the actual rate cannot go below the standard, and therefore the only deviation would be an unfavorable one. Without a union, a personnel official would be responsible. it should be noted that overtime pay, sick pay, vacation pay, etc. are considered indirect labor and therefore a part of overhead.

Efficiency--it is defined as the product of (1) the difference between the labor hours used and the labor hours allowed for the number of units produced and (2) the standard pay. This item is of importance to the supervisor of the particular labor task.

Often times the labor deviations are reported on a single form as follows:

Figure 6

Labor Rate and Efficiency Report[6]
(Hypothetical)

Time Period	Standard Hours	Actual Hours	Deviation (in units)	Deviation (in dollars)	Standard Labor Rate	Actual Labor Rate	Deviation Per Hour	Total Deviation
July	50000	60000	10000	$30000	$3	$2	$1	$60000

C. Overhead deviation

With variable overhead the price deviation is the product of (1) the difference between the actual variable overhead rate per unit (total variable overhead costs divided by total actual hours) and a normal unit rate (the long-run estimate as to the variable overhead rate per hour) and (2) the actual hours. The efficiency deviation is the product of (1) the difference between the labor hours used and the labor hours allowed for the number of units produced and (2) the normal rate.

For fixed overhead, a comparison is made of the total actual costs and the budgeted amount. Control over this item (depreciation, rent, etc.) is usually at a higher level of management than the supervisor.

4.4 Summary

Although a seemingly incidental task, the collecting of the actual performance data is a very important procedure in the control process. First, the data must be related to the individual in charge of the segemnt of the operation. After the particular items have been marked for the supervisor, the necessary calculations must be made to determine the deviations. In the next chapter, the various ways to handle these deviations shall be examined.

FOOTNOTES

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4. Carl Moore and Robert Jaedicke, Managerial Accounting, South-Western Publishing Co., Cincinnati, Ohio, 1967, p. 392.

5. Ibid., p. 393.

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CHAPTER V

INVESTIGATION AND CORRECTION OF DEVIATIONS

5.1 Introduction

With analysis of the data complete, the analyst must decide whether or not to investigate the process. The decision as to how to handle a deviation will depend upon how management perceives the difference from standard. Is the difference sizeable? Can the reason for the deviation be found? Can it be eliminated and at what cost?

To answer these questions, attention shall be directed to four general approaches to the investigation question: (1) the traditional approach, (2) the classical statistics approach, (3) the decision-theory approach, and (4) the Bayesian influence. It should be mentioned that the proposed technique to be applied in the organization under study shall be developed from both the decision-theory recommendations and the Bayesian ideas suggested in this chapter.

As a final note, a brief discussion shall be made into the corrective action stage of the control process. Here, management is concerned with an appropriate course of action, once it receives the information from the investigation.

5.2 Investigation of Deviations

In this section, a survey of the literature shall be made in terms of how deviations from standard are handled.

The scope of this analysis shall range from the traditional methods generally used to the suggested decision-theory approaches.

5.2.1 Traditional approach

In order for management to decide whether it should investigate a deviation (the standard is a single figure), it must have at hand (1) the absolute size of the deviation (either in units or dollars), (2) the relative size of the deviation (3 percent of the standard, for example), and (3) whether the amount is favorable or unfavorable.[1] The isolation of the deviations is a relatively easy task. A more difficult problem arises once the figures are given: which of the deviations are significant enough to be investigated and which ones may be passed over as sufficiently unimportant to warrant an investigation of the causes?

Based on informal conversations with business managers, A. Patrick[2] has concluded that it appears that the investigation of deviations is almost always dependent upon the judgement of the managers. These men using their intimate knowledge of the operations and past experience have developed rough gauges by which they measure performance. They set the outside limits for which deviations are acceptable or not. Any amount above a given number or percent from the standard shall be investigated. It should be pointed out that neither objective evidence nor historical facts may justify the setting of the outside limit. No scientific technique may have been used to determine the significance of the deviation.[3]

In most cases, only the unfavorable deviations are looked at. Management seems to be concerned only with the production performance below the standard. Although investigation of a situation of superior performance might lead to improved conditions elsewhere, nevertheless, management has not been too concerned with this possibility.

If one were to express a phrase which best summarizes the traditional approach, it would have to be "management by exception."[4] With this philosophy, those areas which management believed were going well would not be considered. Only those areas which were abnormally being performed (the exception, that is) would be red-flagged for management. The difference between normal and abnormal would, of course, be settled by management's judgment.

In seeking to discover what most companies do with a deviation, Sord and Welsch[5] have conducted a study of 366 companies, indicating the type of action required when deviations occur:

1. 52% require a written explanation of causes of significant deviations.
2. 36% require an oral explanation of significant deviations.
3. 49% require an indication of the corrective action taken.

4. 66% require a discussion of the significant deviations with the immediate superior.

What is encouraging about these statistics is the deep concern for handling significant deviations. The problem becomes one of defining "significant."

The above type of approach can be used in small operations with great success. However, with an organization where dollar amounts are expressed in millions of dollars, an error in deciding whether to investigate a deviation can prohibit necessary productivity or create unnecessary costs for investigation. Subjectivity in determining the "significant" deviation can produce the wrong decision.

To illustrate this weakness, consider the following example. Suppose management after applying its judgment to the situation sets a 3 percent limitation as the point at which an investigation should be undertaken. It may be that a considerable period passes before a 2 percent boundary will be used, even though the deviation above 2 percent has been around for some time.[6]

Another weakness of the traditional approach is the use of a point-estimate to express the standard. Today, it is generally agreed that various factors (learning, fatigue, age of workers, etc.) will cause acceptable performance to fit some statistical distribution. In order to evaluate actual results, the analysts may have to compare a distribution of actual results with a distribution representing the standard.

Finally, some concern must be made for deviations which are favorable. If, indeed, investigation of these differences reveals an extraordinary behavior, perhaps this information can yield improvements in other departments.

5.2.2 Classical statistics approach

Instead of stating the standard as a point estimate, cost accountants using classical statistics have gone to a range of values to express acceptable performance. The assumption is that manufacturing activities combine, either directly or indirectly, natural resources and human efforts, and that the performance of a production process is subject to much fluctuation and variation.[7]

In effect, the standard becomes a distribution expressing the collection of either physical units or input costs required for the production of a given amount of output. Standard cost is the mean of the distribution. To determine whether actual performance is under control is to determine (1) how far actual performance is from the mean of the controlled distribution (the standard distribution), and (2) whether this deviation is due to chance or some systematic factor.

The first consideration is the form of the statistical distribution representing the controlled performance (the standard). In most cases, the normal distribution is used simply because the performance is normally distributed or because many distributions (for example, the binomial) approach the normal form as the sample size increases. In addition, for practical reasons, by using the normal distribution, calculations are facilitated.

The analysis requires that both the mean and standard deviation for the universe of controlled performance be known. Usually, both are determined from past data adjusted to represent the current situation. Whether the engineer (working for the cost accountant) sets the distribution parameters himself or some form or participation is included to obtain these figues is for management to decide.

Once the controlled distribution has been set, the analyst must look at actual performance. In doing so, two types of deviations from standard may emerge: (1) chance deviation due to random causes, and (2) assignable deviation attributable to systematic causes. It is the analysts' task to compare the actual performance with standard such that the effect of random deviations is eliminated. Only assignable deviations are to be investigated.[8]

Management hypothesizes that favorable and unfavorable deviations due to random causes will fall equally on either side of the mean of the controlled distribution. Considering how far away these chance deviations may fall, the analyst establishes boundaries on either side of the standard mean. Deviations due to non-controllable causes will fall within these boundaries. They are identified and ignored.

Deviations resulting from assignable causes (lying outside the limits) are considered significant and therefore in need for investigation.[9]

Any rule for establishing control limits for use in a manufacturing setting should be a practical one based on experience. In the United States, the control limits are generally placed at three standard deviations on either side of the center line of the distribution.[10] For a normal distribution, this represents 99 percent of the distribution. Therefore, it is believed that any deviation which is more than three standard deviations away from the center line must have occurred other than by chance. It must be investigated.

To test whether actual performance does in fact lie outside three standard deviations from the mean of the controlled distribution, the analyst first sets up what is known as the null hypothesis, in this case that the sample mean (from actual data) is the same as the mean of the controlled distribution. Naturally, in any given sample, the obtained value of the statistic probably will not exactly equal the standard mean. The question becomes: is the deviation between the obtained value and the expected value large enough, in light of the sampling distribution, to make the truth of the hypothesis seem very unlikely?[11] If the deviation is more than three standard deviations away, the analyst concludes that the hypothesis was wrong, that the deviation was not due to chance, and an investigation is necessary.

In order to visualize this hypothesis-testing, the analyst may prepare a control chart which indicates the mean of the controlled distribution, the control limits, and the plotting of the sample means. Points above and below the control limits are deemed out of control and ready for investigation. Employing the control chart, the analyst can also note fluctuations in the sample points as well as viaualize the trend of the sample points as time goes on. Although some sample means may exist within the control limits, it may be that some difficulty reveals itself. While most work with control charts has been in the area of quality control, management is beginning to employ this technique with quantity standards.[12]

There has been some mention in the literature of comparing the entire data distribution with the controlled distribution by taking goodness-of-fit tests. If the controlled distribution is normal, the analyst may use t-tests and F-tests for the comparison. For other types of distributions, F. Luh suggests the use of the Kolmogorov-Smirnov limit theorem.[13]

At a Milwaukee-based manufacturing firm, Frank Probst employed the control chart concept to establish a control system for direct labor cost. An $\bar{x}$ chart was established with control limits placed on either side of a previously specified performance norm three standard deviation points on either side:

3σ

-------------------------- standard cost (center line)

3σ

Foremen were then expected to observe actual performance in order to see how it related to the standard.[14]

Twenty-five random samples of labor cost were taken during the first month of the study. Each sample consisted of four observations, and each observation represented the actual cost per 100 pieces. The means of each sample were then plotted on the control chart to see if in fact they were inside or outside the control limits. Any sample lying outside the limits would be investigated.

In comparing this form of control, hypothesis-testing and the control chart, with the more traditional approach, a few major improvements emerge:

1. There is a more realistic specification of the controlled cost (the standard), since variability of performance is recognized.

2. The unrealistic assumption of uniform performance is eliminated.

3. A thorough analysis of the actual data can be made: average performance, variance, median, mode, skewness, and kurtosis.

4. A quantitative evaluation of the results is achieved. Management now has a more clearly-defined decision rule which

can be used to determine if a deviation should be looked at.[15]

As well as the above considerations, any success of the use of classical statistics depends upon its acceptance by those who must use it. The literature has suggested that participation in the standard-setting is necessary to gain this acceptance, and that once acceptance comes other behavioral advantages emerge (for a complete discussion as to the reasons for standard-setting participation, see Chapter III).

The study by Probst[16] gives evidence that for these statistical techniques participation in the setting of the standard is crucial. In the first section of the study, the control chart was set up without any participation. Despite the apparently favorable results obtained from the use of $\overline{x}$ charts (only three of the twenty-five samples were deemed out of control), the foremen were unwilling to rely upon the charts as decision rules. To a man, they maintained that experience was the only necessary guide to action. Even the fact that they had actively participated in the search for assignable causes failed to change their judgment.

In the second section of the study, Probst allowed the foremen to form the controlled distribution. By means of a questionnaire, the foremen noted the probability that the labor cost would fall within certain ranges (between $3.74

and \$3.78, for example). From the results of the questionnaire, a distribution was formed and a mean and standard deviation were calculated. After preparing a control chart based on this information with boundaries placed at three standard deviations away, the twenty-five samples of actual data from the next month were plotted. In terms of the number of samples considered out of control, because of a more conservative estimate of the universe standard deviation, there were three samples outside the limits (instead of two the previous month).

Although for these two months there appeared similar results, a rather significant benefit was the increased support of the statistical technique of the part of the foremen. Two factors led to this increased support: the participation by the foremen and their understanding of it (because of the participation). The importance of this support cannot be overemphasized, since any success with statistical tools will come first with the foremen of the department. One of the findings of the Probst study was that operating costs cannot be controlled simply by means of a directive from middle management. The control possibilities were realized only when the men directly responsible had endorsed the approach. This endorsement came about only by allowing the foremen to determine the standard distribution.[17]

Besides the effect of participation, expressing the standard as a range instead of merely a single point can bring acceptance by the subordinates for other reasons: In an article by Miles and Vergin[18] these reasons are stated:

A. The use of classical statistics requires a definition of performance based on at least actual data.

B. It creates a certain flexibility around the standards.

C. Subordinates can establish their own performance targets within the control limits.

D. There appears to be the potential for creating a positive atmosphere for the exercise of necessary corrective action. Management's action can be viewed by both parties as problem-solving rather than punitive.

E. The technique is potentially at least both simple to apply and easy to understand.

In another article by B.M. Gross[19] the author notes that control limits leave room for informality. Also, because of a certain vagueness in the goal formulation, the precious element of humanity is restored.

For these behavioral improvements as well as the other improvements already noted, it appears that it is advantageous for management to: (1) express the standard in the form of a range, and (2) employ participation at least by the foremen in the determination of the standard.

Use of classical statistics does bring about a better decision model than the traditional approach. However, for various reasons, this technique too has many weaknesses which must be remedied in order to obtain an effective management tool.

A. Sole Use of Objective Data

with classical statistics, only evidence contained in the sample is used to make the decision. There is little use of subjective data as an additional source of information. Often times, objective evidence may be lacking or too expensive. In addition, the experience of key individuals within the organization which may produce more valuable data, is not taken into account.[20]

B. No Mechanism to Update the Standard

Once the standard distribution is set, the combination of objective and subjective information may reveal the need to change the standard. Using classical statistics, there is no mechanism to update the distributions.

C. Possible Error in the Decision

In either rejecting or accepting the null hypothesis, the analyst is open to two types of possible error: (1) the error of investigating a deviation which is due to random influences (a Type I error) and (2) the error of failing to investigate when there is in fact a non-random deviation from standard (a Type II error). As the analyst changes the control limits to eliminate the possibility of one source of error, the possibility of the other increases. If the absolute amount of the deviation is large, an investigation may have to be made even if the probability of occurrence is small.[21]

D. Cost of unnecessary investigation

In considering whether to make an investigation, the analyst should consider the cost for an investigation. Certainly, if the cost were greater than the deviation, it would not pay to conduct the investigation.

E. Cost of not conducting an investigation

In order to make the decision, the analyst should also be aware of how much the organization loses by not making the investigation when it should have. If the cost for allowing the situation to remain is greater than the cost to eliminate it, then this piece of information should be included in the decision-making process.

5.2.3 Decision-Theory Approach

The modern decision-theorist confronts the problem of whether to investigate a deviation by considering the consequences of alternative decision choices. These consequences, usually expressed in terms of a payoff to the decision-maker (either opportunity costs or losses to him), result from the interaction of two factors: (1) the alternative acts possible for the decision-maker, and (2) the state of the world which actually occurs involving this decision.[22]

As shall be shown, many of the authors who have taken the decision-theory approach have stayed with the classical statistician's assumption that the state of the world can be described by a normal population distribution. For this reason, the contribution of these men is primarily the inclusion of the payoff table expressing the appropriate costs involved with the decision.

In terms of the possible acts for the decision-maker, there are basically two: (1) investigate a deviation, and (2) do not investigate the deviation. Although some authors have argued for levels of investigation (which would increase the possible acts), only the two shall be considered.[23]

To describe what is meant by the state of the world, the analyst must indicate what the decision is based upon. Bierman,[24] in one of the first articles in this area, notes that the decision is dependent upon the cause of the deviation: (1) the deviation was caused by factors beyond the control of management, and (2) the deviation was caused by factors within the jurisdiction and control of management. Alderson and Green,[25] applying the Bierman article to the control of salesmen's budgets, use the same two possible states of nature.

Bierman's state one is referred to as "in control" and state two as "out of control." If the deviation is within three standard deviations from the mean of the standard distribution, then the system is said to be operating in state one, namely "in control." If the deviation is larger than the three standard deviations, then the system is "out of control." Bierman (in an appendix) has suggested dividing the out of control region into two separate areas thus creating three states: (1) in control, (2) a favorable region to the right of the three standard deviations, and (3) an unfavorable region to the left. However, since Bierman uses only the two states in his article, only "in control" and "out of control" will be used.

Both the Bierman and Alderson and Green articles illustrate how probabilities can be assessed for the two states of nature. The objective here is to calculate the conditional probability that the system is in/out of control given that an unfavorable deviation is discovered. If a favorable deviation is discovered, at this point the decision-rule is to do nothing (the author's model shall remove this assumption).

From probability theory, it is well known that P(B/A) = P(A B)/P(A) where B = system is out of control given an unfavorable deviation is 1 - P(B/A).[26] The analyst wishes to determine these probabilities.

Using only the two states of nature, the marginal probability for an unfavorable deviation, P(A), is designated .5. Actual results above the budgeted mean are out of control and those below are in control (this assumption can also be relaxed). To calculate the joint probability, that is, the system is in control and the deviation is unfavorable, the analyst must first determine how many standard deviation points the actual result is from the standard (finding the Z-value). Once this has been done, it is a simple task to use the cumulative normal tables to calculate the probability of being that many standard deviations from the budgeted mean (same as used in classical statistics). Dividing this probability, P(A B), by P(A), the conditional probability for state 1 is determined. So is the conditional probability for state 2.[27]

Once the acts and probabilities for the states of nature have been spelled out, the analyst must next seek to quantify the consequences for each combination. This is usually done by formulating a payoff table consisting of the set of payoffs for all possible combinations of actions and states of nature.[28]

In the literature there has been an attempt to at least express the payoff table in literal form. It has already been noted that one major contribution for this study will be the operationalization of such a payoff table. In any case, Bierman puts forth the following payoff table:

In order to see how this approach does work, consider the application by Alderson and Green (the figures are all hypothetical). Seeking to control salesmen's expenses, they first set the standard distribution with budget mean at $150 and standard deviation at $30. If it is assumed that unfavorable and favorable random (non-controllable) deviations from this mean are approximately equally likely, then it is possible to call this distribution normal.[33]

Next, they established the payoff table:

Table 6

Alderson and Green's Payoff Table (Expressed as Costs)

	S_1	S_2
A_1 Investigate	5	5 + D
A_2 Do not investigate	0	2D

where Cost of Investigation = $5
Cost of Correction = The deviation
Opportunity loss = Twice the deviation (in the example it is believed the organization loses $2 per unit of deviation with no investigation).

Faced with uncertainty concerning S_1 and S_2, the analyst must assess probabilities for the states of nature. Taking a sample of nine salesmen's expenses, the mean was calculated at 170 and the standard deviation of the sample ($\sigma/\sqrt{n}$) was determined to be 10. Standardizing the distribution to learn how many standard deviation points the sample is from the budget mean, a Z-value is calculated, namely $(\overline{x}-\mu)/\sigma_{\overline{x}}$ =

(170 - 150)/10 = 2. To obtain the conditional probability of being in control given the unfavorable deviation (namely $20), the analyst must divide the joint probability (in control and unfavorable deviation) by the marginal probability (unfavorable deviation). Using the cumulative normal tables, the joint probability (with Z at 2) is .023. The conditional probability for S_1 would therefore be .023/.5 or .046, and the conditional probability of S_2 would be 1 - .046 or .954.[34]

The decision-rule says to compare the two expected costs. In this case, they would be:

$$\text{Expected cost } (A_1) = .046\ (5) + .954\ (5 + 20) = \$24.18$$
$$\text{Expected cost } (A_2) = .046\ (0) + .954\ (2 \times 20) = \$38.16$$

The result is that management should investigate, since this expected cost is lower than that of doing nothing.

5.2.4 Bayesian Influences

Any credibility in the decision-theory approach depends upon the credibility of the probability assessments for S_1 and S_2. In the example above, only one sample of nine was used to determine these probabilities. To gain a more meaningful assessment of these probabilities, all available information besides sampling data should be used. The meachnism used to combine sample data with other information is Bayes Theorem. Since the Bayesian will use sampling distributions of the classical statistician, and in addition, other information, the Bayesian approach can be thought of as an extension of the classical approach.[35]

Classicalists assert that the parameter (whether the system is in/out of control) is not a random variable. They say that any possible value considered for it either is or is not the correct one. To them, all probabilities should be based on the long-run frequency interpretation of probability, and therefore subjective probabilities are not admissable. Subjectivists, on the other hand, do think of the parameter as a random variable and thus allow probability statements concerning it. To these people, all information is welcome. If a Bayesian has determined probability estimates for S_1 and S_2 and additional information influences him to change the initial assessment, he will.[36]

As a first step, an a priori probability assessment concerning the states of nature is formulated. This distribution may be based on judgmental factors of the analysts or objective information from past data. This distribution describes the decision-maker's state of information or degree of belief as to the several different conceivable values that the unknown parameter may take. It is held by the individual before any sampling is taken.[37]

In classical statistics, all inferences are based on the sampling distribution with this resulting distribution often referred to as the likelihood function. With the Bayesians, the sampling also produces a likelihood function, but it actually is the likelihood of the prior distribution with the likelihood function to produce a posterior probability distribution. This distribution summarizes the state of knowledge or belief of the decision-maker after he has made use of additional information gained through sampling.

For the Bayesian, the process can continue with each new sampling or judgmental belief giving a new likelihood function. The posterior distribution from the first round becomes the a priori distribution for the next round. To determine how long the process should continue, the analyst must compare the cost of sampling with the increased value of the information.[38]

To illustrate the use of Bayesian statistics in decision theory, consider M. Onsi's example of controlling defective units of material.[39] Assume the following payoff table with two possible acts, four states of nature, and the a priori distribution stated above each state of nature:

Table 7

Onsi's Payoff Table
Combination of Acts and Probability Assessments for States of Nature

	.5 State 1	.2 State 2	.2 State 3	.1 State 4
A_1 Accept	1	5	10	15
A_2 Reject	4	4	4	4

Computing the expected costs, the expected cost of acceptance is $5.00 and the expected cost of rejection is $4.00. Therefore, the optimal decision is to reject the process and investigate.

Now suppose an additional sample is taken with the likelihood function as follows:

Table 8

Onsi's Likelihood Probabilities[40]
From Sampling

	Likelihood
State 1	.818
State 2	.358
State 3	.122
State 4	.039

Combining the likelihood function with the a priori distribution, the posterior distribution becomes .804, .141, .048, and .007. Determining expected costs again, the expected cost (A_1) = \$2.094 and the expected cost (A_2) = \$4.00. At this point, because of the additional information the optimal act becomes accepting the process and taking no action.

To determine whether the additional sampling was advantageous, the analyst computes the expected loss for each act under the prior distribution and then the posterior distribution. In Onsi's example, the loss table appears as follows:

Table 9

Onsi's Loss Table
Conversion of Table 7

	State 1*	State 2	State 3	State 4
Act 1	0	1	6	11
Act 2	3	0	0	0

*Note: Loss (Act 1, State 1) = Cost (Act 1, State 1) - Lowest cost (State 1) = 1 - 1 = 0

Loss (Act 2, State 1) = Cost (Act 2, State 1)
- Lowest cost (State 1) = 4 - 1 = 3

Multiplying these losses by the respective probability distributions, the analyst would have expected losses for acceptance and rejection for each distribution. The expected losses under the prior distribution would be \$2.50 (acceptance) and \$1.50 (rejection). For the posterior probabilities, the expected losses would be \$.51 (acceptance) and \$2.41 (rejection).[41]

The value of information obtained from this sample is equal to the reduction of the cost of uncertainty, which is the expected loss of the optimal decision given a probability distribution. With the prior distribution, the expected loss is \$1.50 (it was determined to reject the process). With the posterior distribution, it is \$.51 (it was determined to accept the process). Therefore, the value of information is approximately \$1.00. If the cost of a sample was higher, then the additional sampling was unjustified.

A decision-theory approach using Bayesian statistics appears to improve upon both the traditional and classical approaches in handling the deviation problem. Summarizing the characteristics of this modern technique, the following benefits accrue:

1. There is a de-emphasis of the hypothesis-testing approach to the decision (comparing the sample mean with the population mean). Instead, the decision is based on prior

belief, sample evidence, possible additional sampling, and the economic loss of each combination of act and state of nature.

2. Subjective assessments are incorporated into the analysis usually through prior distributions.
3. There is no requirement to determine the alpha and beta risks of error as is done in classical statistics. Instead, the economic importance of each is put into the analysis through the prior distribution, the likelihood function, and the payoff table.
4. By comparing the sampling cost with the value of information, it is possible to obtain an optimum sample size.
5. Finally, and most importantly, the entire decision route is formalized. Each alternative is evaluated and expressed in terms of the best action possible.[42]

5.3 Correction of the Deviations

If it is believed that the system is out of control and an investigation required, then the results of the investigation will aid in determining the corrective action.

Often times, the problem may have been a one-shot affair, such as an electrical storm, which caused the deviation for this period, but which will probably not occur in the future. therefore, although the investigation reveals the fact that the electrical storm was the problem, no corrective action is necessary.

On the other hand, if the problem is one which might occur in the future and affect future operations, then it must be handled. As illustrations of these possible problem areas, which the supervisor of an operation might wish to correct, are the following:

A. Improper handling
B. Inferior quality of material
C. Poor workmanship
D. Changes in methods
E. Untrained workers
F. Slow machines
G. General inefficiencies in the worker

On occasion, the investigation of a deviation may result in the belief that the standard itself is unreasonable. If the figure linking the different phases of the control process is recalled (Figure 1, Chapter II), one remembers that the correction phase of the control process (the last item) is linked to the first, setting the standard. Therefore, when conditions change so that the standard is believed unreasonable, the correction process will indicate that the standard must be adjusted.

In either case, whether the standard remains the same or is adjusted, the control process functions in the same way in the following period. Data for that period will be assembled and analyzed, and then the supervisor will face the decision whether the operation should be investigated and the problem areas corrected.

5.4 Summary

Now that the data has been assembled and analyzed, the supervisor of the particular segment of the organization has had to make the decision as to what should be done with deviations from standard.

In order to correct the problem underlying the deviation, the supervisor must have an idea as to what is wrong. The general approaches discussed in this chapter are different ways in which the supervisor can handle the investigation decision. Based on the evidence in the literature, it appears that the decision-theory approach,with Bayesian influence is the one means of considering the various factors which influence the decision. For that reason, the proposed technique shall be developed from the decision-theory models discussed in the chapter.

To mention the last phase of the control process, correcting the problem, it was noted that the significant question to be answered is whether the correction can help future operations. If it can, then the supervisor will desire to tackle the problem.

FOOTNOTES

1. Mohammed Onsi, "Quantitative Models for Accounting Control," The Accounting Review, April, 1967, p. 321.

2. A.W. Patrick, "A Proposal for Determining the Significance of Variations from Standard," The Accounting Review, Oct., 1957, p. 587,

3. Ibid., p. 588.

4. G.H. Hofstede, The Game of Budget Control, Assen, Netherlands Royal Van Gorcum, Ltd., 1967, p. 36.

5. Hofstede, p. 36. Also see Sord and Welsch, Business Budgeting, A Survey of Management Planning and Control Practices, New York Controllership Foundation, Inc., 1958, p. 33.

6. Patrick, p. 588.

7. F.S. Luh, "Controlled Cost: An Operational Concept and Statistical Approach to Standard Costing," The Accounting Review, Jan., 1968, pp. 123-124.

8. Onsi, p. 322.

9. Ibid., p. 322.

10. E.L. Grant, Statistical Quality Control, McGraw-Hill Book Company, 1964, p. 90.

11. For a detailed description of hypothesis testing, see W. Hays and R. Winkler, Statistics: Probability, Inference, and Decision, Holt, Rinehart, and Winston, Inc., 1971, pp. 375-377.

12. Control charts were originally developed for use in quality control. For a complete description of quality control see D. Cowden, Statistical Methods in Quality Control, Prentice-Hall, Inc., 1957, pp. 1-5, and E.L. Grant, Statistical Quality Control, McGraw-Hill Book Company, 1964, pp. 3-16.

13. Luh, p. 131. For a description of curve-fitting tests as well as the Kolmogorov-Smirnov limit theorem see Hays and Winkler, pp. 778-852, especially pp. 817-821.

14. Frank R. Probst, "Probabilistic Cost Controls: A Behavioral Dimension," The Accounting Review, Jan., 1971, p. 113.

15. Luh, p. 130.

16. Probst, p. 115.

17. Ibid., p. 118.

18. Hofstede, pp. 102-103. See Miles and Vergin, "Behavioral Properties of Variance Controls," California Management Review, 1966, pp. 57-65.

19. Hofstede, p. 103. See B.M. Gross, "What are Your Organization's Objectives?", Human Relations, London, 1965, pp. 195-216.

20. Onsi, p. 324.

21. Ibid., p. 322.

22. Hays and Winkler, p. 511.

23. For a complete description of a three act possibility, see R.T. Dyckman, "The Investigation of Cost Variances," Journal of Accounting Research, Autumn, 1969, pp. 228-230.

24. H. Bierman, L. Fouraker, and R. Jaedicke, "A Use of Probability and Statistics in Performance Evaluation," The Accounting Review, July, 1961, p. 414.

25. W. Alderson, and P. Green, Planning and Problem Solving in Marketing, Richard D. Irwin, Inc., Homewood, Illinois, 1964, Chapter 12, p. 349.

26. Hays and Winkler, p. 84.

27. For a complete description of the possible ways to handle states of nature under uncertainty, see Hays and Winkler, pp. 516-523.

28. Hays and Winkler, p. 514.

29. Bierman, p. 414.

30. Alderson and Green, pp. 342-343.

31. Hays and Winkler, p. 514.

32. Dyckman, p. 219.

33. Alderson and Green, p. 342.

34. _Ibid._, pp. 342-346.

35. Hays and Winkler, p. 445.

36. _Ibid._, pp. 448-449.

37. Jack Hirshleifer, "The Bayesian Approach to Statistical Decision--An Exposition," _The Journal of Business_, October, 1961, p. 472.

38. For a complete explanation of the value of information see Hays and Winkler, pp. 551-562.

39. Onsi, p. 327.

40. _Ibid._, p. 328.

41. _Ibid._, pp. 327-329.

42. _Ibid._, p. 324.

CHAPTER VI

A TECHNIQUE TO HANDLE THE DEVIATION PROBLEM

6.1 Introduction

To develop a management tool which can handle the deviation investigation question will entail a synthesization and extension of the information presented up to this point. From the previous chapters, it has been shown that the standard itself must be carefully considered. Factors such as participation in the standard-setting must be incorporated. Once the standard has been formulated, the literature has suggested the use of a decision-theory approach in handling deviations from standard. Keeping these thoughts in mind, this chapter shall be a formulation of the theoretical model.

Before starting, it should be repeated that the application of this model (in the next chapter) will focus on a particular labor requirement for a specific manufactured item. However, although examples and illustrations may relate to a labor requirement, the analysis can apply equally to any other cost element.

This chapter shall focus on the six elements of the decision-theory technique: (1) the distribution representing initial expected average performance (the mean of which equals the standard), (2) the states of nature and their initial probability assessments, (3) the payoff table, (4) initial expected costs, (5) the value of information and optimum sample size, and (6) updated probability assessments.

6.2 Initial expected average performance

Management's first task in controlling operations is to establish the standard. While it is possible for management to select tight, loose, or attainable standards, this model shall assume a standard equal to what management initially expects average performance to be. Although the evidence in the literature proved inconclusive in terms of selecting a type of standard, it was hinted that extremely tight standards could prove harmful. By using an average performance level as the standard, the figure should be perceived as reasonable by both management and by the workers.

For this reason, the first step is to identify this initial expected average performance (expected can be equated with anticipated). Whatever this figure, the same amount shall represent the standard. Once the standard is set, it does not change unless management so decrees. To change the standard often would cause many behavioral problems. It is so important that the workers perceive the standard as fixed.

Although the expected average performance figure will be initially equal to the standard, it will change as new information is brought in to revise it. This revised figure will be used later to assess the actual level of performance with any difference between this figure and the standard of utmost concern.

6.2.1 The Engineer

Because the engineer does have a thorough knowledge of what performance will be, the first input into obtaining the initial estimate as to average performance shall be his advice. Realizing that all workers will not perform at the same rate, this engineer is asked to come up with a distribution of outputs reflecting the expected performance of the average worker. The mean of this distribution will be his estimate of average expected performance, and the standard deviation shall reflect the precision of the mean. To obtain this information, a questionnaire is administered to the engineer.

As a reference point in establishing this distribution, the analyst begins with a level of maximum efficiency. This is true since the engineer may be most familiar with the maximum output of a given machine or a particular labor requirement. Therefore, at the start of the questionnaire, the engineer might be asked, "Under ideal conditions, that is, when there is no allowance for learning, shrinkage, waste, machine breakdown, etc. (100% efficiency), how many units do you believe an average worker should be able to complete as to the desired task in one hour?"

Since the analyst is interested in the mean of the distribution, that is, the average expected performance, he must somehow adjust the 100% efficiency level. Based on the knowledge and experience of management, each organization will select a percentage factor which does allow for waste, shrinkage, learning, etc., so that the resulting efficiency level (for example, 95% efficiency) reflects this average expected performance.

An important point to be made here about the engineer's distribution is that it is considered a sampling distribution. Although subjectively determined, the 95% figure from the questionnaire (the mean of the engineer's distribution) is thought of as the average of a large number of sample means estimating the true mean (the true level of actual performance). The standard deviation is in fact the standard error of this sampling distribution. With this in mind, it is concluded from the central limit theorem that the distribution (because of the theoretically large sample) approximates a normal distribution. In effect, the analyst has employed a subjective sampling device to estimate the true mean.

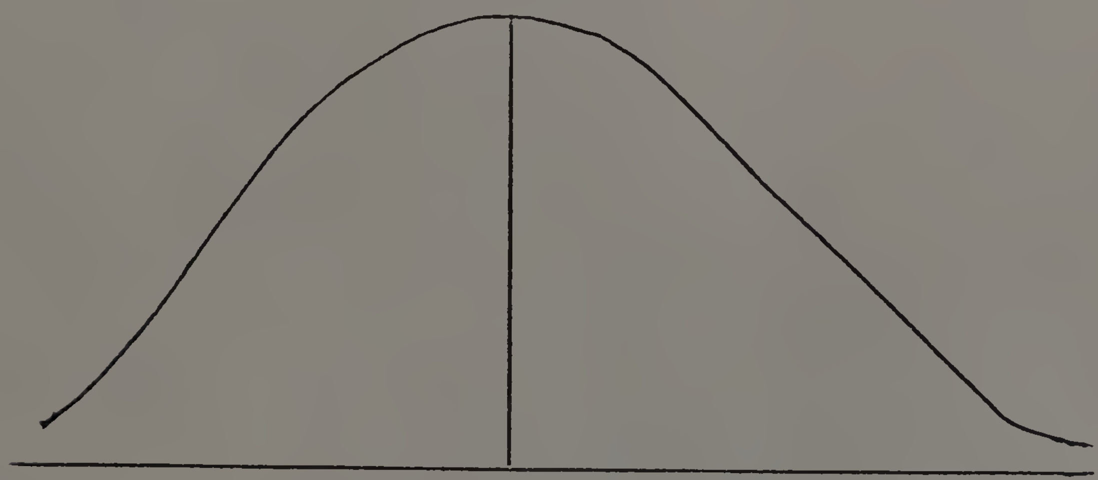
To determine the standard deviation of this normal distribution, the engineer is asked about dispersion of performance. For example, the engineer might be asked, "For an average worker there will be fluctuations in the number of items completed (in terms of a specific labor requirement) above and below the mean. Around this mean, indicate a range within which you are reasonable sure an average worker will perform 50% of the time."

Once a reply is given, the resulting figure can be easily converted to a number of standard deviation points. Using the 50% figure, the analyst knows that from a normal distribution the figure obtained through the questionnaire would represent two-thirds of a standard deviation. Therefore, by dividing the obtained figure by two-thirs, the analyst has determined the standard deviation.[1]

As a result of the above analysis, one distribution for average performance is formulated:

Figure 7

Expected Average Performance
Engineer's Estimate



μ_0 = (95% efficiency, for example)

σ_0 =

6.2.2 The Supervisor

A need for participation in the standard-setting has been carefully demonstrated. The Probst article[2] among numerous others insisted upon the participation by supervisors to insure the success of any implementation of a statistical technique. Therefore, since the initial expected performance distribution will be used to establish the standard, some adjustment must be made to reflect the supervisor's judgment.

To carry out this revision, the supervisor for the given labor requirement is administered a similar questionnaire as received by the engineer. Through the same process as with the engineer, a second distribution is formulated.

In statistical terms, this second distribution is also treated as if it were a sampling distribution. For Bayesian analysis, it is as if the information from the second questionnaire yields a sampling distribution of $\bar{x}$'s with mean designated $\bar{\bar{x}}$ and standard deviation $\sigma(\bar{\bar{x}})$.[3] It should be noted that this resulting distribution also approximates the normal:

6.2.3 The Combination

Now that the analyst has developed two distributions, one from information given by the engineer and one from information given by the supervisor, he will want to combine the two. This resulting distribution, known as the initial posterior distribution, is important since it represents both the standard distribution and at the start the expected average distribution.

To combine the two distributions, the analyst makes use of normal conjugate theory. If the first subjective distribution is normal (the engineer's distribution is so designated), then the posterior distribution will also be a normal distribution with the following mean and standard deviation:

1. Posterior mean--weighted average of the two means, the

   the weights being: $(1/\sigma_0^2)/\frac{1}{\sigma_0^2} + \frac{1}{\sigma^2(\bar{x})}$

   and $(1/\sigma(\bar{x})^2)/\frac{1}{\sigma_0^2} + \frac{1}{\sigma^2(\bar{x})}$.[4]

$$\mu_1 = \frac{\mu_0/\sigma_0^2 + \bar{x}/\sigma^2(\bar{x})}{1/\sigma_0^2 + 1/\sigma^2(\bar{x})}$$

2. Posterior variance--the reciprocal of the posterior variance is the sum of the reciprocals of the variances of the two distributions.

$$\frac{1}{\sigma_1^2} = 1/\sigma_0^2 + 1/\sigma^2(\bar{x})$$

As a numerical example, consider a distribution with mean and standard deviation: $_0=200$ and $\sigma_0=8$ (determined by a questionnaire given to the engineers). From the second questionnaire given to the supervisors, the mean is determined to be 180 and the standard deviation 10.

Therefore:

1. <u>Posterior mean</u>

$$\mu_1 = \frac{200/64 + 180/100}{1/64 + 1/100} = \underline{\underline{192}}$$

2. <u>Posterior variance</u>

$$1/\sigma_1^2 = 1/64 + 1/100 = \underline{\underline{.025}}$$

3. <u>Posterior deviation</u>

$$\sigma_1 = 1/\sqrt{.025} = \underline{\underline{6.25}}$$

Considering the above example, the posterior mean lies between the prior mean and the sample mean. In this case, it was closer to the engineer's estimate because that standard deviation of 8 was smaller than that of the supervisor, namely 10. What happens is that the engineer's estimate is given a greater weight. The assumption is made that the smaller deviation was caused by the engineer's estimate of the true mean coming from a larger sample of the population. One would expect as the sample size increases, the smaller standard deviation would reflect this "zeroing in" on the true mean.

In an application of this model, it is important that when the standard is initially being set (that is, the determination of the posterior distribution) the questionnaires be administered independently to the engineer and supervisor. Management must seek to eliminate any political play in completing the questionnaires.

The posterior standard deviation is smaller than either of the component deviations. To explain this point, think of both the prior mean and sample mean as "estimates" of the true mean and also think of the weights (reciprocals of the variances) as actual measures of the "quantity of information" underlying these estimates.[5] With both distributions normally distributed:

$I_0 = 1/\sigma_0^2$: the quantity of information summarized by μ_0

$I_{\bar{x}} = 1/\sigma^2(\bar{x})$: the quantity of information summarized by $\bar{x}$

Using the posterior variation equation, the quantity of information summarized by μ_1, namely I_1, will equal $I_0 + I_{\bar{x}}$. As a result, I_1 must be greater than either I_0 or $I_{\bar{x}}$ and in turn the reciprocal of I_1, namely the posterior variance, is necessarily less than either σ_0^2 or $\sigma^2(\bar{x})$.

In setting the standard, participation was carried out by the engineer and supervisor. If one were to add participation by the workers, an additional sampling distribution would be formulated (using a similar questionnaire), and the same updating would take place to come up with a new posterior distribution. With this model, the particular level of participation was used for two reasons. First, the Probst article[6] argues only for participation by the supervisors. Secondly, in the application to follow, it was not feasible to administer the questionnaire to the workers.

6.2.4 Control limits

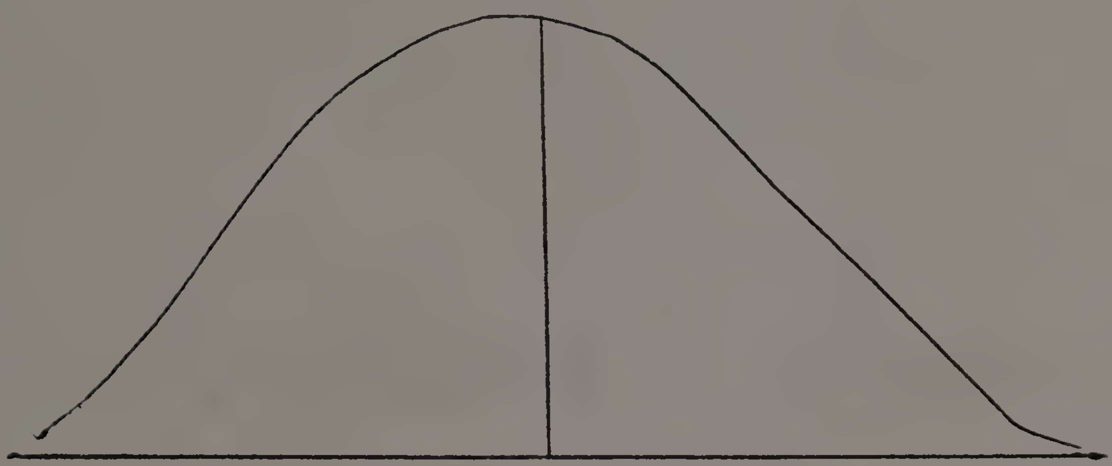
While the mean of the initial posterior distribution represents the standard to the workers (in the example, 192), the evidence in the literature suggests a range of allowable output. Therefore, the analyst must now establish control limits on either side of the posterior mean within whose boundaries performance is ruled acceptable. If management in fact knew that actual performance was in this region, then it would conclude that the system were "in control". If performance lies below the lower control limits, the system is deemed "unfavorably out of control". If it is above the upper control limit, then it is "favorably out of control".

In order to set the control limits, the analyst and those assisting him must select a figure which both they and the workers perceive as reasonable. It has already been pointed out that the success of a technique such as this one depends upon the acceptance by the subordinates (both supervisors and workers). Selecting a round figure such as 5% (determined by management) as an allowance on either side of the posterior mean would be both understood and perceived as reasonable.

To illustrate the above, consider the initial posterior

Figure 8

Expected Average Performance
Supervisor's Extimate



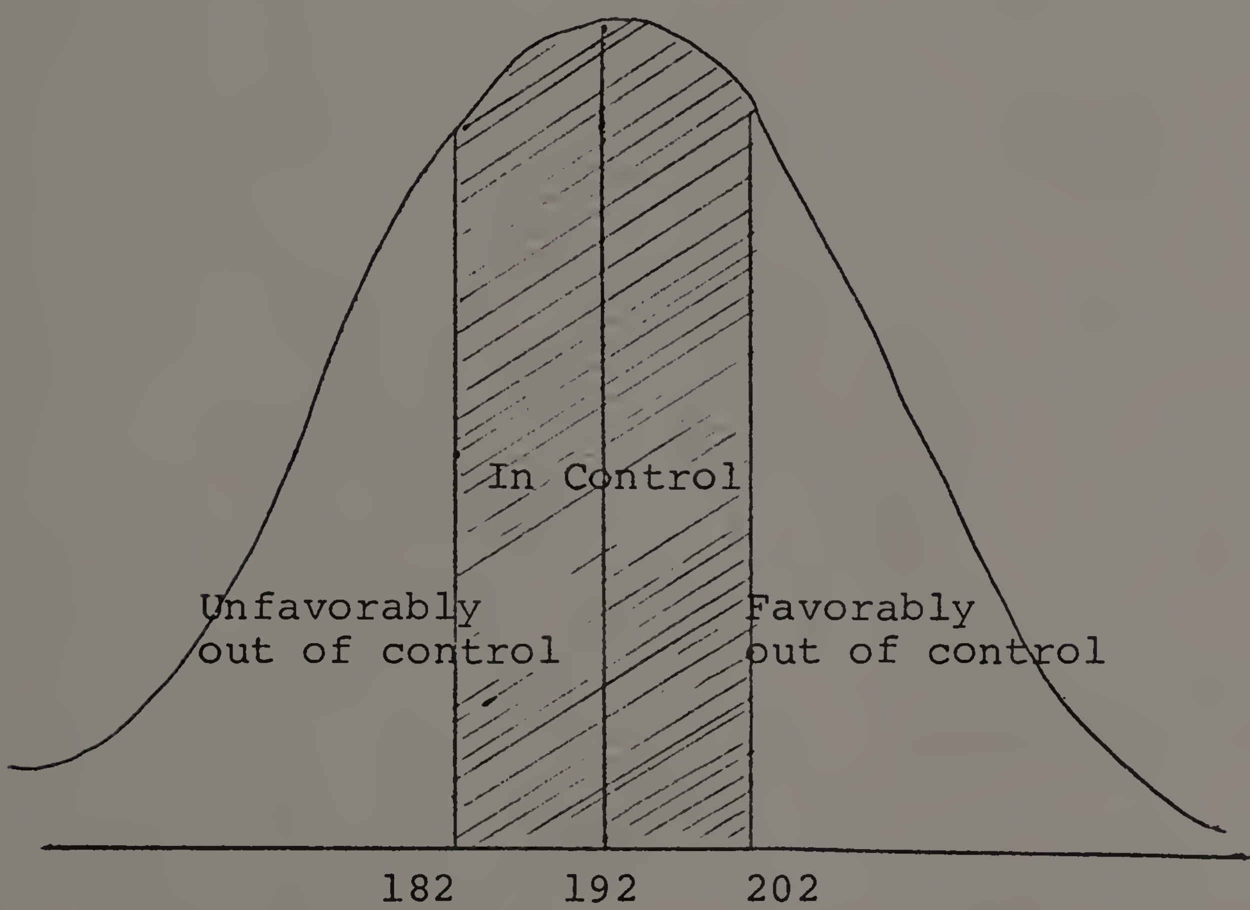
$\bar{\bar{x}} =$ (95% efficiency, for example)

$\sigma(\bar{\bar{x}}) =$

distribution from above with mean at 192 and standard deviation at 6.25. If a 5% allowance is chosen, the control chart would be as follows:

Figure 9

Standard Distribution
Combination of Engineer and Supervisor Estimates



Performance lying from 182 through 202[7] is designated "in control," and all performance outside that area is ruled "out of control". More specifically, to the left of 182 units per time period the system is said to be "unfavorably out of control". To the right of 202 units the system is designated as "favorably out of control". The analyst seeks to discover where in fact actual performance lies, for the decision-rule he will follow depends upon this.

6.3 States of Nature and Prior Distribution

If the analyst knew for certain where performance did lie (the true state of nature), then given that value he could compare the cost of investigation with some opportunity cost of no investigation. While the quantification of these costs shall be made in the next section, it must be pointed out that the task is more formidable, since the analyst is unsure as to the true state of nature.

The analyst is not informationless, however, since the standard was determined by a distribution which represents what the engineer and supervisor believe performance will be. Therefore, there is prior information available--the initial posterior distribution.

Because this subjective distribution does provide evidence as to the true state of nature, it is used as the prior for the first period. The prior mean represents an estimate as to average performance and the prior standard deviation represents the precision of the estimate. Therefore, using the same illustration as before, the prior mean for the first month is 192, and the prior standard deviation is 6.25.

6.4 Payoff Table

At this point, it is necessary to establish a payoff table which identifies the costs involved in terms of the two acts (investigate and not investigate) and the three states of nature (in control, unfavorably out of control, and favorably out of control).

Below is this payoff table:

Table 10

Payoff Table (Literal Representation)

	S_2 (unfavorable)	S_1 (in control)	S_3 (favorable)
A_1: Inv.	$C+P(\mu_x)(m_1)$	$C+K+P(\mu_x)(m_3)$	$C+P(\mu_x)(m_1)$ $-PH(\mu_x-L_2)$
A_2: No inv.	0	$PH(L_1-\mu_x)$	$-PH(\mu_x-L_2)$

where C = Cost of investigation

K = Cost of correction

m_1 = Time spent on investigation

m_2 = Time spent on correction

$m_3 = m_1 + m_2$

P = Loss per unit

μ_x = True state of nature

L_1 = Lower control limit

L_2 = Upper control limit

H = Hours in the period

The payoff functions represented in Table 10 can also be stated as follows:

$$C(A_1,\mu_x) = \begin{cases} C+K+P(\mu_x)m_3 \\ C+Pm_1(\mu_x) \\ C+Pm_1(\mu_x)-PH(u_x-L_2) \end{cases} \quad \text{if} \quad \begin{cases} \mu_x<L_1 \\ L_1\leq\mu_x\leq L_2 \\ \mu_x>L_2 \end{cases}$$

$$C(A_2,\mu_x) = \begin{cases} PH(L_1-\mu_x) \\ 0.0 \\ -PH(\mu_x-L_2) \end{cases} \quad \text{if} \quad \begin{cases} \mu_x<L_1 \\ L_1\leq\mu_x\leq L_2 \\ \mu_x>L_2 \end{cases}$$

where $C(A_n,\mu_x)$ is the cost for each act given the true state of nature (n=1,2). It is a random variable, since μ_x is a random variable according to $N(\mu_1,\sigma_1)$.

The next step shall be to consider each of the cells within the payoff table.

6.4.1 $\underline{A_1 \text{ and } S_1}$

6.4.1.1 Cost of investigation (C)

To determine the cost of investigation, the analyst must know: (1) the time it will take to carry out this investigation, (2) who will perform it, and (3) the amount of pay given to these people.

6.4.1.2 Lost Profit because of investigation ($P\mu_x m_1$

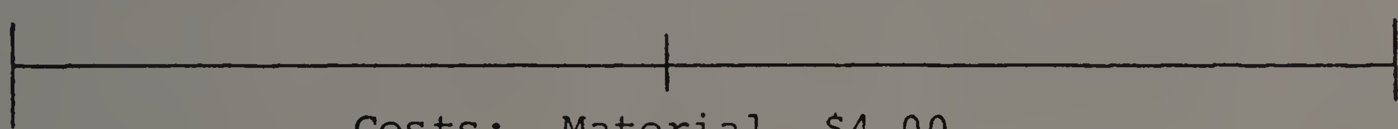
In computing the lost profit per unit for not completing a desired task, three assumptions shall be made. First, it shall be assumed that all items are saleable. In other words, if an item is partially complete and left as work-in-process, when it is completed it shall be sold. For most mass produced items, this is generally the case. Secondly, it shall be assumed that the turnover for the item is high. If an item is not fully completed in one period (for example, a month), then in the following period it will be both completed and sold. In this way there is no need to consider the time value of money. Lastly, it is assumed that the department being analyzed uses cost as the transfer price. In most manufacturing operations, this is also the case.

With these thoughts in mind, the value of P (lost profit per unit) becomes the expenses from the point of concern to the finish of the product. To give an illustration, consider the following:

Figure 10

Loss Per Unit Determination

Start Point of Concern Finish



Costs:	Material	$4.00
	Labor	1.25
	Overhead	.75

Examining the costs at the point of concern, it should be pointed out that while material cost is variable per unit, labor and overhead are usually variable per hour. Therefore, to obtain the $1.25 and $.75 figures (for labor and overhead), it was necessary to divide a long-run estimate of total labor and overhead by a long-run estimate of forecasted productivity at the point of concern (determined by the budget committee). If, for example, it is estimated that the total direct labor and overhead bill at the point of concern will be \$200,000 for the year, and it is estimated that 100,000 units will be completed in the year, then the labor and overhead unit cost would be \$2.00. For every unit which is not completed at the point of concern, there is the inability to absorb this \$2.00 figure. As a result, \$2.00 is the opportunity loss per unit.

One final note is that included in the expenses is the amount of overhead. Since in the long run these costs must be absorbed and since the items not completed will not have to absorb the overhead costs for the next period, it is believed the analyst should include this figure.

Whatever time it takes to conduct the investigation (and thereby causing a loss of time in performing the required task), a certain number of units (at the point of concern) will not be completed. Therefore, the analyst next wishes to know the amount of time needed to conduct the investigation (m_1). If the posterior mean represents the number of units that will probably be completed in the time period (for example, one hour), then μ_x times m_1 represents the number of units which will not be done. Multiplying this number times P gives the additional cost of conducting the investigation.

6.4.2 $\underline{A_1 \text{ and } S_2}$

6.4.2.1 <u>Cost of investigation (C)</u>

(See section 6.4.1.1)

6.4.2.2 Cost of correction (K)

Here, the analyst must determine the cost of correcting the problem for times when the system is in fact "unfavorably out of control." In most cases, this cost will depend upon the specific problem. To handle this, the analyst after listing the major causes of error, the cost to eliminate each, and the probability of each possible cause occurring, computes an expected cost of correction. If the probabilities for the causes of deviation change significantly from one period to the next, the analyst may wish to change the probabilities. Usually, the major reasons are few in number and management (through experience) can make a reasonable estimate as to the probabilities.

6.4.2.3 Lost Profit because of investigation and correction ($P\mu_x m_3$

In this case besides the time necessary to find the problem, there is also the time spent on the correction of it (m_2). Therefore, the total time taken away from completing units (at the point of concern), namely m_3, times μ_x times P gives the additional cost of conducting the investigation and correcting the problem.

6.4.3 A_1 and S_3

(See section 6.4.1.1)

6.4.3.2 Lost Profit because of investigation ($P\mu_x m_1$)

If the system has a distinctive favorable deviation, it is assumed that this time is the same as the time required to learn the reason for an unfavorable deviation. Therefore, the lost profit is $P\mu_x m_1$.

6.4.3.3 Opportunity gain $(-PH(\mu_x - L_2))$

While any favorable deviation might be investigated in order to learn how unfavorable deviations are kept in check, management does not wish to alter this situation. Here, the department is completing more units for a given task than even the upper control limit. This extra production, the difference between the posterior mean and the upper control limit $(\mu_x - L_2)$ multiplied by the profit per unit (same P as before) represents this gain per hour. To determine the total amount gained, the analyst must multiply this figure by the number of hours the system will remain out of control (H). In this example, it was assumed that investigation decisions occur at the end of each month. Now let it be also assumed that if the system is out of control and is not fixed, it will stay that way at least until the next decision. Therefore, the analyst must multiply $P(\mu_x - L_2)$ times the number of workable hours in the following month.[8]

6.4.4 A_2 and S_1

No Cost

6.4.5 A_2 and S_2

6.4.5.1 Opportunity loss $(PH(L_1-\mu_x)$

In this case, the difference between the lower control limit and the posterior mean $(L_1-\mu_x)$ represents the number of units not complete as to a specific labor requirement yet desired to be completed. This number multiplied by the lost profit per unit (P) gives the cost per hour to the company for not conducting an investigation when in fact the system is "unfavorably out of control". When this figure is multiplied by the number of working hours in the next period (H), the total loss is obtained.

6.4.6 A_2 and S_3

6.4.6.1 Opportunity gain $-PH(\mu_x-L_2)$

(See section 6.4.3.3)

6.5 Initial Expected Costs

In order to calculate the expected cost for each act, it is necessary to combine the initial posterior distribution, $N(\mu_1,\sigma_1)$ with the values in each cell of the payoff table. As a result, the following analysis is made:

$EC(A_1,\mu_x)$ = Expected cost of each act given $C(A_n,\mu_x)$ as noted in section 6.4.

Therefore, where $w = f(\mu_x)$ and $f(w) = \frac{1}{2\pi\sigma} \cdot e^{-1/2\left(\frac{w-\mu_1}{\sigma_1}\right)^2}$

$$EC(A_1,\mu_x) = \int_{-\infty}^{L_1} [C + K + P\ m_3(w)]f(w)dw$$

$$+ \int_{L_1}^{L_2} [C + P\ m_1(w)]f(w)dw$$

$$+ \int_{L_2}^{\infty} [C + P\ m_1(w) - PH(w-L_2)]f(w)dw$$

and

$$EC(A_2,\mu_x) = \int_{-\infty}^{L_1} PH(L_1-w)f(w)dw + \int_{L_2}^{\infty} -PH(w-L_2)f(w)dw$$

Let $F(L_1) = \int_{-\infty}^{L_1} f(w)dw$ and $F(L_2) = \int_{-\infty}^{L_2} f(w)dw$

Therefore,

$$EC(A_1\mu_x) = (C+K)F(L_1) + Pm_3\int_{-\infty}^{L_1} wf(w)dw$$

$$+ C[F(L_2)-F(L_1)] + Pm_1\int_{L_1}^{L_2} wf(w)dw$$

$$+ [C+PHL_2][1-F(L_2)] + [Pm_1-PH]\int_{L_2}^{\infty} wf(w)dw$$

and

$$EC(A_2,\mu_x) = PHL_1F(L_1) - PH\int_{-\infty}^{L_1} wf(w)dw$$

$$+ (PHL_2[1-F(L_2)] - PH\int_{L_2}^{\infty} wf(w)dw$$

In solving for $\int_a^b wf(w)dw = \frac{1}{\sqrt{2\pi}\ \sigma} \int_a^b we^{-1/2}(\frac{w-\mu_1}{\sigma_1})^2 dw$

Let $s = \frac{w-\mu}{\sigma_1}$, $dx = \frac{dw}{\sigma_1}$

Therefore,

$$\int_a^b wf(w)\,dw = \frac{1}{\sqrt{2\pi}} \int_{\frac{a-\mu_1}{\sigma_1}}^{\frac{b-\mu_1}{\sigma_1}} (\sigma_1 x+\mu_1)\, e^{-1/2x^2}\,dx$$

$$= \frac{1}{\sqrt{2\pi}} \left[\sigma_1 \int_{\frac{a-\mu_1}{\sigma_1}}^{\frac{b-\mu_1}{\sigma_1}} xe^{-1/2x^2}\,dx + \mu_1 \int_{\frac{a-\mu_1}{\sigma_1}}^{\frac{b-\mu_1}{\sigma_1}} e^{-1/2x^2}\,dx \right]$$

$$= \frac{\sigma_1}{2\pi} \left[-e^{-1/2x^2} \right]_{\frac{a-\mu_1}{\sigma_1}}^{\frac{b-\mu_1}{\sigma_1}} + \mu_1 \left[F\left(\frac{b-\mu_1}{\sigma_1}\right) - F\left(\frac{a-\mu_1}{\sigma_1}\right) \right]$$

$$= \frac{\sigma_1}{\sqrt{2\pi}} \left[-e^{-1/2(\frac{b-\mu_1}{\sigma_1})^2} + e^{-1/2(\frac{a-\mu_1}{\sigma_1})^2} \right]$$

$$+ \mu_1 \left[F\left(\frac{b-\mu_1}{\sigma_1}\right) - F\left(\frac{a-\mu_1}{\sigma_1}\right) \right]$$

To solve for the three possible valuations for $\int_a^b wf(w)\,dw$ given the three sets of values for "a" and "b", the following was determined:

where $B1 = \int_{-\infty}^{L_1} wf(w)\,dw$

$B2 = \int_{L_1}^{L_2} wf(w)\,dw$

$$B3 = \int_{L_2}^{\infty} wf(w)dw$$

$$B1 = \frac{\sigma_1}{\sqrt{2\pi}}\left[-e^{-1/2(\frac{L_1-\mu_1}{\sigma_1})^2} + e^{-1/2(\frac{-\infty-\mu_1}{\sigma_1})^2}\right] + \mu_1\left[F(\frac{L_1-\mu_1}{\sigma_1})-F(\frac{-\infty-\mu_1}{\sigma_1})\right]$$

$$= \frac{\sigma_1}{\sqrt{2\pi}}\left[-e^{-1/2(\frac{L_1-\mu_1}{\sigma_1})^2}\right] + \mu_1\left[F(\frac{L_1-\mu_1}{\sigma_1})\right]$$

$$B2 = \frac{\sigma_1}{\sqrt{2\pi}}\left[-e^{-1/2(\frac{L_2-\mu_1}{\sigma_1})^2} + e^{-1/2(\frac{L_1-\mu_1}{\sigma_1})^2}\right] + \mu_1\left[F(\frac{L_2-\mu_1}{\sigma_1})-F(\frac{L_1-\mu_1}{\sigma_1})\right]$$

$$B3 = \frac{\sigma_1}{\sqrt{2\pi}}\left[-e^{-1/2(\frac{\infty-\mu_1}{\sigma_1})^2} + e^{1/2(\frac{L_2-\mu_1}{\sigma_1})^2}\right] + \mu_1\left[F(\frac{\infty-\mu_1}{\sigma_1})^2-F(\frac{L_2-\mu_1}{\sigma_1})\right]$$

$$\doteq \frac{\sigma_1}{\sqrt{2\pi}}\left[e^{-1/2(\frac{L_2-\mu_1}{\sigma_1})^2}\right] + \mu_1\left[1-F(\frac{L_2-\mu_1}{\sigma_1})\right]$$

In summary,

$$EC(A_1,\mu_x)^2 = [C+K)F(L_1) + Pm_3 \cdot B1$$
$$+ C(F(L_2)-F(L_1)] + Pm_1 \cdot B2$$
$$+[C+PHL_2][1-F(L_2)] + [Pm_1-PH]B3$$

and

$$EC(A_2,\mu_x) = (PHL_1F(L_1)-PH\cdot B1$$
$$+ PHL_2[1-F(L_2)] - PH\cdot B3$$

Using the initial posterior distribution (μ_1=192 and σ_1=6.25), the same standard and control limits (standard = 192, and L_1=182, L_2=202), and the following hypothetical payoff table, initial expected costs were calculated:

Table 11

Payoff Table (Numerical Example)

	S_2(unfavorable	S_1(in control)	S_3(favorable)
A_1: Inv.	$20+33+2(\mu_x)(1)$	$20+2(\mu_x)(.5)$	$20+2(\mu_x)(.5)$ $-2(\mu_x-202)(320)$
A_2: No inv.	$2(182-\mu_x)(320)$	0.0	$2(\mu_x-202)(320)$

where C=20

K=33

P = 2

$m_1 = .5$

$m_2 = .5$

$m_3 = m_1+m_2 = 1.0$

H = 320

To determine expected costs, note the following:

$$EC(A_1,\mu_x) = [20+33]F(182) + (2)(1)(B1)$$
$$+ 20\ [F(202)-F(182)] + (2)(.5)(B2)$$
$$+ [20+2(320)(202)][1-F(202)]$$
$$+ [2(.5)-2(320)](B3)$$

and

the next section, the task will be to determine whether and how much additional information is required in order to revise these expected cost figures.

6.6 Value of Information and Optimum Sample Size

6.6.1 Expected Value of Perfect Information (EVPI)

Before determining the optimal sample size of actual performance data, it is necessary to compute the value purchase of "perfect" information (that is, perfect knowledge as to the true state of nature). Obtaining this figure, the analyst knows the maximum he would spend for any additional sample.

With perfect information, the decision-maker (the analyst) operates under certainty and is therefore interested in the losses (or loss functions) for the two acts given the true state of nature. As has been stated before, the amount of loss for each act (assuming the true state of nature is known) is the difference between the optimum act and all other acts (see Table 9--Chapter III).

In this particular model, the state of nature designated "unfavorably out of control" must be first split into two regions since the optimal act under S_2 depends upon how far the true state of nature is from the lower control limit. To compute this cutoff point (say $\mu_x=T$) and thereby establish the boundary line dividing S_2, the following calculation is made (equating the two payoffs from Table 10--S_2 region):

$$C + P\ {}_x m_3 + K = PH(L_1 - \mu_x)$$

$$\mu_x = \frac{PHL_1 - C - K}{Pm_3 + PH} = T$$

To clarify the above point, it should be said that under certainty about S_2, the optimum decision depends upon whether μ_x (the true state of nature) is in the area between the cut-off point and the lower control limit or in the area to the left of the cutoff point. In each case, the optimal decision is different, and therefore the losses are different.

Converting the payoff table (Table 10) to a loss table the following results appear:

Table 12

(Loss Table (Literal Representation)

	Way out of control $\mu_x \leq T$	Out of control $T < \mu_x < L_1$	In control $L_1 \leq \mu_x \leq L_2$	Favorable $L_2 < \mu_x$
A_1:	0	$C+P\mu_x m_3+K-PH(L_1-\mu_x)$	$C+Pu_x m_1$	$C+P\mu_x m_1$
A_2:	$PH(L_1-\mu_x)-(C+P\mu_x m_3+K)$	0	0	0

The loss functions represented in Table 12 can also be stated as follows:

$$L(A_1,\mu_x) = \begin{cases} 0.0 & \mu_x \leq T \\ C+K-PHL_1+(PH+Pm_3)\mu_x & \text{if} \quad T < \mu_x < L_1 \\ C+P(m_1)\mu_x & \mu_x \geq L_1 \end{cases}$$

$$L(A_2,\mu_x) = \begin{cases} (PHL_1-C-K)-(PH+Pm_3)\mu_x & \text{if} \quad \mu_x \leq T \\ 0.0 & \mu_x > T \end{cases}$$

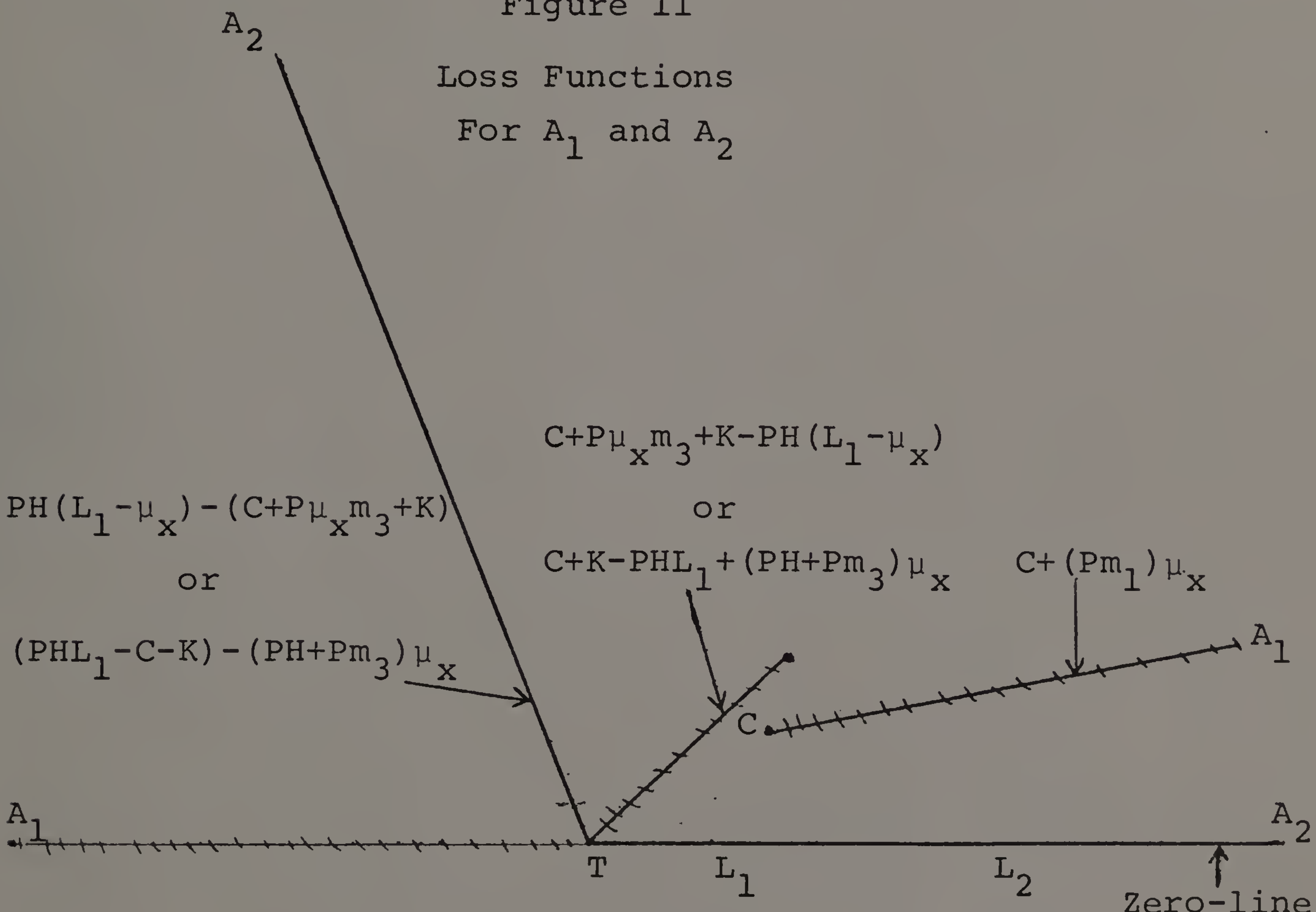
where $L(A_x, \mu_x)$ is the loss under each act. It is a random variable, since μ_x is a random variable according to $N(\mu_1, \sigma_1)$.

In graph form, the above functions convert to the following figure (the coefficients of μ_x are the slopes of the loss functions):

Figure 11

Loss Functions

For A_1 and A_2



Consider the above figure. Because of the steep slope of A_2 to the left of the cutoff point, the organization looses considerably as it is discovered that the true state of nature is to the left (and the selected act is A_2).

Between the cutoff point and the lower control limit, the loss for investigating is equally as great, yet this area may be quite small. Finally, for the region to the right of L_1, the slope of loss function for selecting A_1 is much flatter. Let it be noted that the loss function for the "favorably out of control" region (S_3) reduces to the same loss function as for S_2.

From the manner in which the losses were determined, the optimal act under certainty always has a zero loss (note Table 12). Therefore, if one had perfect information (knows the true state of nature), he will suffer no opportunity loss. Because the analyst is in a state of uncertainty, there must be some expected loss associated with the two possible acts. This amount, the expected value of perfect information, the analyst seeks.

Before taking any samples, the analyst has at hand only the initial posterior distribution by which to assess probabilities for S_1, S_2, and S_3. Therefore, using this information alongside the loss functions found in Figure 11, he can compute an expected loss of perfect information. This figure will be the maximum he would spend for any sample.

In determining EVPI, the analyst takes the following steps:

1. The mean of the current posterior distribution is used to assess the true state of nature (the analyst determines

it to be S_1, S_2, or S_3).

2. Given this determination, the analyst selects the optimum act (A_1 or A_2).

3. Using the loss function associated with <u>that</u> act, he calculates the expected loss.

To determine the particular expected loss, note the following:

$EL(A_n,\mu_x)$ = expected loss of act $n(n=1,2)$ given $L(A_n,\mu_x)$ as described in section 6.6.1

Therefore, where $f(w) = \frac{1}{\sqrt{2\pi}\,\sigma} \cdot e^{-1/2\left(\frac{w-\mu_1}{1}\right)^2}$

$$EL(A_1,\mu_x) = \int_T^{L_1}[(C+K-PHL_1) + (PH+Pm_3)w]f(w)\,dw$$

$$+ \int_{L_1}^{\infty}[C+Pm_1w]f(w)\,dw$$

$$= [C+K-PHL_1][F(L_1)-F(T)] + [PH+Pm_3]\int_T^{L_1} wf(w)\,dw$$

$$+ C[1-F(L_1)] + Pm_1\int_{L_1}^{\infty} wf(w)\,dw$$

and

$$EL(A_2,\mu_x) = \int_{-\infty}^{T}[(PHL_1-C-K) - (PH+Pm_3)w]f(w)\,dw$$

$$= [PHL_1-C-K]F(T) - [PH+Pm_3]\int_{-\infty}^{T} wf(w)\,dw$$

Evaluating the three possibilities for

$$\int_a^b wf(w)\,dw = \frac{1}{2\pi}\left[-e^{-1/2\left(\frac{b-\mu_1}{\sigma_1}\right)^2} + e^{-1/2\left(\frac{a-\mu_1}{\sigma_1}\right)^2}\right] + u_1\left[F\left(\frac{b-\mu_1}{\sigma_1}\right) - F\left(\frac{a-\mu_1}{\sigma_1}\right)\right]$$

namely $Y1 = \int_{-\infty}^{T} wf(w)\,dw,$

$Y2 = \int_{T}^{L_1} wf(w)\,dw,$ and

$Y3 = \int_{L_1}^{\infty} wf(w)\,dw,$

$$Y1 = \frac{1}{\sqrt{2\pi}}\left[-e^{-1/2\left(\frac{T-\mu_1}{\sigma_1}\right)^2}\right] + \mu_1\left[F\left(\frac{T-\mu_1}{\sigma_1}\right)\right]$$

$$Y2 = \frac{1}{\sqrt{2\pi}}\left[-e^{-1/2\left(\frac{L_1-\mu_1}{\sigma_1}\right)^2} + e^{-1/2\left(\frac{T-\mu_1}{\sigma_1}\right)^2}\right] + \mu_1\left[F\left(\frac{L_1-\mu_1}{\sigma_1}\right)-F\left(\frac{T-\mu_1}{\sigma_1}\right)\right]$$

$$Y3 = \frac{1}{\sqrt{2\pi}}\left[+e^{-1/2\left(\frac{L_1-\mu_1}{\sigma_1}\right)^2}\right] + \mu_1\left[1-F\left(\frac{L_1-\mu_1}{\sigma_1}\right)\right]$$

In summary,

$$EL(A_1,\mu_x) = [C+K-PHL_1][F(L_1)-F(T)] + [PH+Pm_3]Y2$$
$$+ C[1-F(L_1) + Pm_1(Y3)$$

$$EL(A_2,\mu_x) = [PHL_1-C-K]F(T) - [PH+Pm_3]Y1$$

To illustrate the calculation of EVPI, consider the figures for the initial posterior distribution as determined during this chapter:

where: $\mu_1 = 192$ and $L_1 = 182$

$\sigma_1 = 6.25$

$L_2 = 202$
$C = 20$
$K = 33$
$m_1 = .5$
$m_2 = .5$
$P = 2$
$H = 320$

$$\text{Cutoff Point} = \frac{PHL_1 - C - K}{Pm_3 + PH}$$

$$= \frac{2 \times 320 \times 182 - 20 - 33}{2 \times 1 + 2 \times 320}$$

$$= \underline{\underline{181.35}}$$

Since the estimate of μ_x is 192 and the corresponding optimum act for that value is A_2 (at μ_x=192, $L(A_2)$=0.0), the valuation for EVPI will be the calculation of $EL(A_2, \mu_x)$:

$$EL(A_2, \mu_x) = (2 \times 320 \times 182 - 20 - 33)\ F(181.35)$$
$$- (2 \times 320 + 2 \times 1)\ Y1$$

$$\text{where } Y1 = \frac{6.25}{\sqrt{2\pi}} \left[-e^{-1/2 \left(\frac{181.35-192}{6.25}\right)} \right] + 192\ [F(181.35)]$$

Using the computer program marked EXPT (found in Appendix C), the following calculation was made:

EVPI = \$69.93

Now, the analyst knows that he will not pay more than \$69.93 for the additional information.

6.6.2 Expected Value of Sample Information (EVSI)

Unfortunately for the decision-maker, perfect information is unavailable. Instead, the analyst considers whether to take samples of actual performance to use to update the initial posterior distribution and thereby reduce the state of uncertainty. Because this sampling will entail some cost, the analyst must determine the value of the sample information and compare it to the cost of sampling.

It should be first noted that the expected value of sample information can never be greater than the expected value of perfect information since sample information can never be any better than perfect information.[10] In the previous section the losses were determined under the assumption that the true state of nature was known. Now, that assump- is removed. As the size of the prospective sample increases, the EVSI will approach EVPI. For this reason, the EVPI (in the sample, \$69.93) acts as an upper limit for EVSI.

To determine EVSI, the analyst begins with his initial posterior distribution (mean = μ_1 and variance = σ_1). Selecting a particular sample size of n, he calculates the reduction in variance caused by this additional sample.[11]

$$1/\sigma_2^2 = 1/\sigma_1^2 + n/\sigma^2 = \frac{\sigma^2 + n\sigma_1^2}{\sigma_1^2\ \sigma^2}$$

where σ_2^2 = updated posterior variance

^{2} = population variance[12]

and therefore:

$$\sigma_2^2 = \frac{\sigma_1^2\ \sigma^2}{\sigma^2+n\sigma_1^2}$$

The reduction in variance becomes:

$$\sigma_*^2 = \sigma_1^2 - \sigma_2^2$$

$$= \sigma_1^2 - \frac{\sigma_1^2\ \sigma}{\sigma^2+n\sigma_1^2}$$

$$= \frac{n\sigma_1^4}{\sigma^2+n\sigma_1^2}$$

Once σ_*^2 is determined, the analyst takes the square root of this figure and places the resulting figure, into the same EXPT program as before. Therefore, using the initial posterior mean, μ_x, and the reduction in standard deviation, σ_*, the average expected loss calculated in the program represents EVSI for that value of n.

As an illustration, consider the initial posterior distribution where μ_1=192 and σ_1=6.25. As is shown in Table 12, as the sample size, "n", increases, the reduction in variance (and standard deviation) also increases. In addition, the EVSI becomes larger as the sample size is increased. The next task shall be to select the optimum sample size.

Table 13

EVAI for Various Sample Sizes

n	σ_*	EVSI
1	3.6	1.35
5	5.28	28.53
10	5.7	44.98
15	5.8	50.35
20	6.0	55.52
25	6.01	57.72
30	6.05	61.12
50	6.13	67.52
75	6.16	68.22
100	6.18	69.00
200	6.25	69.93

6.6.3 Cost of Sampling (CS)

Now that various EVSI's have been determined, the analyst must compare these figures to the cost of conducting the sampling. In computing this cost, the following must be considered:

1. Computer Time) COMP)

   This amount would reflect first any sign-on time on the teletype necessary to calculate EVPI and various EVSI's (multiplying the sign-on time by the cost per time period for sign-on time). Secondly, the time taken by the teletype operator times that person's pay per hour would reflect the expense for the operator's time. Both costs would generally be independent of the sample size.

2. Sampling Time--Fixed (WF)

   Whatever the sample size selected, there will be some initial time taken for a worker to take the instructions from the computer operator, find the appropriate records for the period, select the random sample as indicated, and make the necessary calculations (find the updated posterior mean and variance). Multiplying this time by the appropriate pay per hour would represent the fixed sampling cost.

3. Sampling Time--Variable (WV)

   Admittedly, it would take more time and effort to conduct the sampling as the sample size increases, as the worker must obtain a larger number of observations. This additional time would be reflected in the taking of the extra random samples. When this time is multiplied by the appropriate pay, the variable sampling cost is determined.

The cost of sampling, then, can be assumed to approximate the following linear function:

$$CS(n) = COMP + WF + WV(n)$$

The difference between the EVSI and CS for each level of "n" is designated the expected net gain of sampling (ENGS).[13] The analyst selects that sample size with the highest value for ENGS.

For purposes of illustration, assume the following hypothetical figures:

Computer sign-on time	= 1 hour
Computer operator's pay	= \$4.00 per hour
Rental cost for computer	= \$25.00 per hour
Sampling time-fixed	= 1 hour
Sampling time-variable	= 10 minutes
Sampler's pay	= \$3.00 per hour

Therefore:

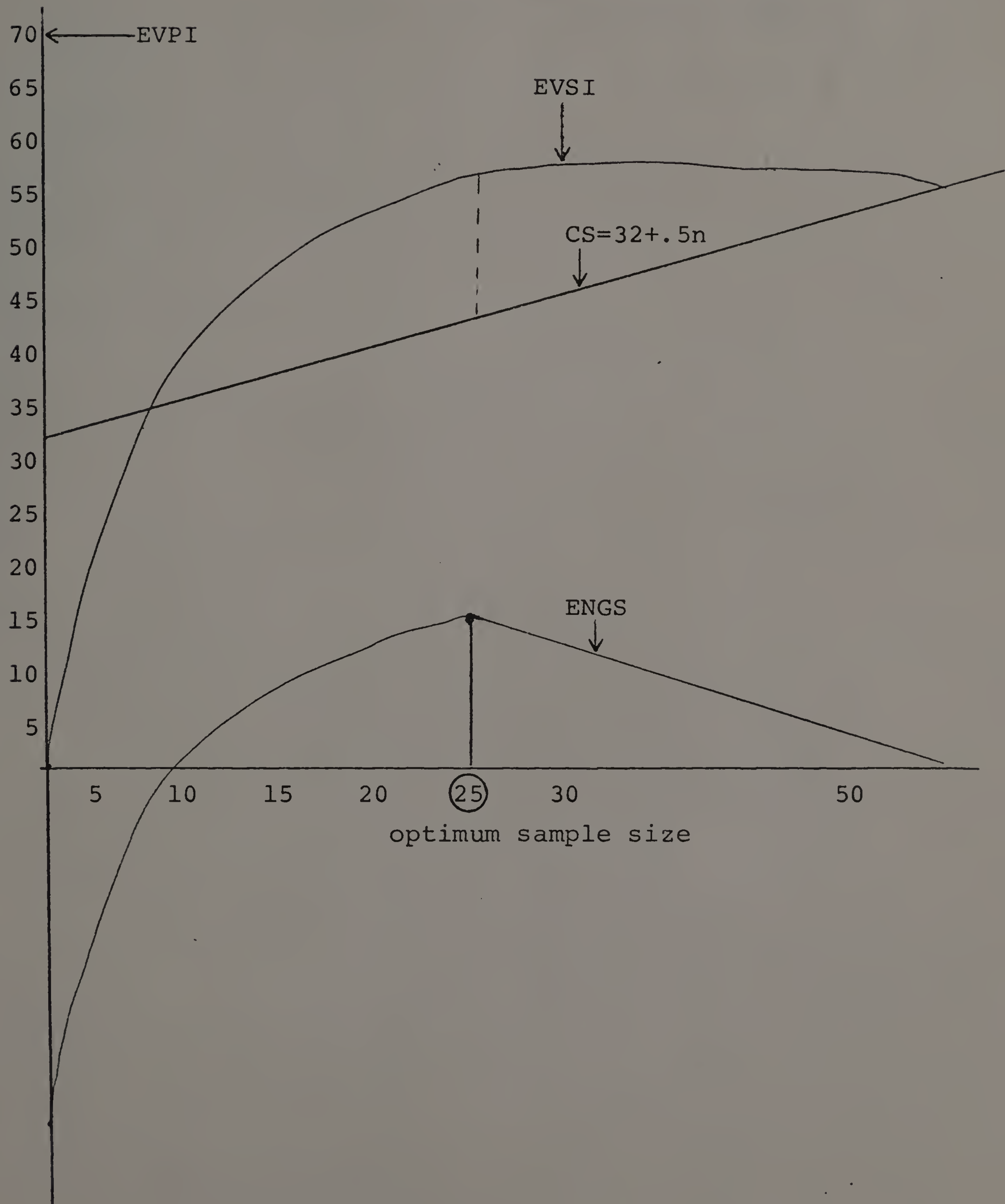
$$CS(n) = \$25 + \$4 + \$3 + \$.50(n) = 32 + .5n$$

To obtain the optimum sample size, the analyst should select that "n" in which the difference between EVSI and CS is greatest (the highest point on the ENGS curve). In the above example, it would appear that the optimum n is approximately 25.

Figure 12

EVSI, CS, and ENGS

$u_1=192$ and $\sigma_1=6.25$



In determining the maximum value for sample size, the analyst finds as a constraint the number of checks on actual performance made during the period. For example, if checks on actual performance were made every hour, with one worker working on the given labor requirement, two 8-hour shifts per working day, and twenty working days per month, then 320 checks would have been made during the period. In this case, the analyst could sample until he had exhausted the 320 observations.

6.7 Updating the Prior

Assume from the previous section that the optimum sample size was 25. Having taken a hypothetical sample of actual performance data, the following calculations were made:

$$\bar{\bar{x}} = 163$$

$$s(\bar{\bar{x}}) = 25$$

$$\sigma(\bar{\bar{x}}) = s/\sqrt{n}\ 25/\sqrt{25} = 5$$

The above mean and standard deviation have been determined from a sampling distribution representing a distribution of means (in this case, sample size equals 25) whose grand average is 163 and whose sampling deviation is 5. Because of the central limit theorem, this distribution like the other approximates a normal distribution.

Combining the two distributions using the same procedures as was done in combining the engineer's distribution with the supervisor's (section 6.2.3) the following calculations are made:

$$\mu_2 = \frac{192/39 + 150/25}{1/39 + 1/25} = 174$$

$$1/\sigma_2^2 = 1/39 + 1/25 = .0656$$

$$\sigma_2 = \underline{\underline{3.92}}$$

In evaluating the above results, first consider the new posterior mean (174). From the initial figure of 192, it has shifted way down to 174. One reason is the 163 figure produced from the actual data (the sample). It appears that the 192 value was not representative of what average performance would be. To explain the extreme shift, one should note the amount of information supplied from the sample (I_x=1/25) which is greater than the amount of information coming from the initial distribution (I_0=1/39). This forced the shift to be closer to the 163. As explained previously, the new posterior standard deviation (3.92) is smaller than the prior standard deviation (6.25) and the sample deviation (5).

With the previous sample of 25, the EXPT computer program is applied to the combination of the posterior distribution (μ_2=174 and σ_2=3.92) and the cells of the payoff table. Using that program, the following calculations were made:

EC(inv.) = \$397

EC(No inv.) = \$5190

The decision-rule, based on more information as to the true state of nature, now dictates that an investigation be taken.

At this point, with a revised estimate of μ_x, the analyst would recalculate various levels of EVSI, CS, and ENGS to determine whether additional sampling should be undertaken. Ending this process when the optimum sample size is determined to be zero or the maximum number of observations has been exhausted, the analyst would then use the most recent updated posterior distribution coupled with the payoff table to determine the expected cost of investigation and no investigation. The optimum act is to select the lower.

6.8 The Next Month

At the end of the next month, the analyst will be faced with the same investigation question. What information he uses in this decision will depend upon: (1) whether an investigation was taken in the previous month, and (2) whether the standard was changed.

If an investigation occurs and the standard is to be changed, then the entire process of determining the standard and initial posterior distribution is carried out again. The prior distribution for month two is the new initial posterior distribution. If, however, and investigation occurs, the problem area corrected (the system is brought back into control), but the standard is left alone, then the prior distribution for month two is the subjective prior distribution.

If no investigation had been taken in the previous month (whether a correct or incorrect decision), the analyst in the next month has both past and current data from which to assess the true state of nature (actual performance). A complicating factor which arises is the possibility that the true state of nature may be fluctuating from period to period causing the worth of past information to deteriorate as time passes. As a result, the analyst must search for the optimum combination of past and current information.

Although the current month's data is the closest in time to the true state of nature, the analyst in a given decision period also has a prior belief, and it is argued that this prior belief is a valid input into the probability assessment. In judging this prior belief, it is suggested that it originated from the previous month's sampling data.

To demonstrate the above point as well as to see the implications of using the previous month as the prior, consider the various possibilities for the previous month. If last month's data had indicated poor performance, yet no investigation had been taken (that month's prior was high), then this month's current data, if also high, will offset last month's information which was probably not representative of the current true state of nature (therefore, no investigation will be necessary). If, however, the current month also indicates poor performance, then the combination of two inadequate performance levels will demand an investigation. Had the high performance level of two month's ago been included in the prior for this month, it is possible that the current two months' low performance levels would still demand no investigation.

FOOTNOTES

1. Robert Schlaifer, Probability and Statistics for Business Decisions, McGraw-Hill Book Company, Inc., New York, 1959, pp. 438-439.

2. Frank Probst, "Probabilistic Cost Controls: A Behavioral Dimension," The Accounting Review, January, 1971.

3. Schlaifer, p. 441.

4. Ibid., p. 441.

5. Ibid., p. 441.

6. Probst, p. 113.

7. To facilitate the acceptance of the technique, the standard and control limits were rounded off to the nearest whole unit (192, 182, and 202 units, respectively).

8. For a discussion as to the procedures taken when this assumption is removed, see T.R. Dyckman, "The Investigation of Cost Variances," Journal of Accounting Research, Autumn, 1969, pp. 228-230.

9. It should be pointed out that this cutoff point cannot be greater than L_1:

   As $(C+K) \to \infty$, $\mu_x \to 0.0$

   $(C+K) \to 0.0$, $\mu_x \to PHL_1/(Pm_3+PH)$

   As $m_3 \to \infty$, $\mu_x \to 0.0$

   $m_3 \to 0.0$, $\mu_x \to L_1$

10. Robert Winkler, Introduction to Bayesian Inference and Decision, Holt, Rinehart, and Winston, Inc., New York, 1972, p. 306.

11. Ibid., pp. 363-365.

12. To estimate the population variance for this subjective prior, the following calculation is made:

   $$\sigma^2 = n\sigma_1^2$$

   where σ_1^2 = the initial posterior variance
   n = 2 (the questionnaires given to one engineer and one supervisor)

   It should be noted that this calculation is very conservative since σ^2 will be twice σ_1^2; see Winkler, pp. 284-285.

13. Winkler, p. 310.

CHAPTER VII

APPLICATION OF THE MODEL

7.1 Introduction

Having presented the theoretical model, it would be beneficial to test its workability in the real world. Therefore, working with a large New England manufacturing company, necessary data was obtained for the operationalization of the proposed management tool. However, because of various constraints on the present investigation (to be explained), only one direct labor requirement of a particular process shall be considered.

In discussing this labor requirement, it would be advantageous to consider: (1) a general overview of the firm, (2) the rationale used in selecting the particular labor function under study, and (3) the present control process. Given the above discussion, attention can then be directed toward the operationalization of the proposed technique.

7.2 General Overview of the Firm[1]

The company under study is a wholly owned subsidiary of a large oil company in the United States.[2] With its main office in the mid-west, there are approximately 50,000 employees working for this large manufacturing organization.

In each branch of the subsidiary, the type of item manufactured is a fabricated plastic. For example, in the Tennessee plant, various types of plastic brushes are made. On the West Coast, translucent building material (used for overhead awnings, for example) is manufactured. At the Ohio plant, only injection plastics are made.

At the New England site is found the largest plant of the subsidiary. With almost 2300 employees working in total as much as three shifts per day, various types of brushes and plastics are produced. Finding a typical monthly sales volume of one million dollars for its brush plant alone, this plant is considered one of the larger factories in the area.

Examining its manufacturing divisions, one finds three:

A. Brush division--It manufactures household brushes and personal type brushes (tooth brushes, hair brushes, etc.)

B. Injection plastics division--With a remolding process using thermo-plastic, it produces items such as plastic handles for brushes and custom plastic items (television fronts, for example).

C. Compression plastics division--With a nonremolding process called thermo-setting, this division produces items such as plastic dinnerware.

In terms of the physical structure, there are six buildings:

A. Brush plant--It includes both the manufacturing and packaging of the brushes.

B. Injection plant

C. Compression plant

D. Thermo-setting plant--It produces the thermo-setting plastics used for the compression items.

E. Centralized warehouse--It is involved with the housing of the items from the three manufacturing enterprises and the shipping.

F. Administrative office

For the New England plant to achieve effective control over its manufacturing operations, it must handle the three elements of cost, material, labor, and factory overhead. To visualize the enormous size of this task, note the following outline which sketches the kinds of items which must be considered:

A. Direct Materials

1. Brushes
    a. Two kinds of filaments
        (1) Nylon (made in the brush plant)
        (2) Natural fibers (more expensive, purchased in foreign markets)
    b. Handles (made in the injection plant)
    c. Stapling wire (made of nickel steel, aluminum, or copper, it is purchased)
    d. Packaging materials
        (1) Containers
        (2) Blister packaging (sheet material is purchased and formed here for hair brushes, household brushes, and combs)
    e. Related materials
        (1) Display cards (purchased)
        (2) Corregated cartons (mostly purchased, some are manufactured here)

2. Injection plastics
   a. Crystals--polyprophelene, acetate, nylon, and stirene (all purchased in crystal form)
   b. Colorents--powder, dye (all purchased)
   c. Finishing materials--lacquers, paint, and stamping foil

3. Compression plastics
   a. Chemicals--formaldihide, celluloise paper (specially processed), mellamine crystals, and colorents
   b. Decorative designs--they are added to the plates
   c. Packaging materials
      (1) Display containers
      (2) Shrink film packages
   d. Corregated boxes for shipping

B. Direct Labor

1. Brush plant
   a. Stapling--this includes the operation of a machine to insert filaments into the handles
   b. Finishing--this includes stamping the handle, trimming the brush (both machine done) and shipping (hand done)

2. Plastics (both injection and compression)
   a. Molding--operator at a machine brings together the dyes
   b. Finishing
      (1) Stamping (machine done)
      (2) Painting (both machine and hand done)

C. Indirect Labor (overhead)

1. Machine adjusters and set-up men
2. Plant maintenance people (carpenters, plumbers)
3. Service people (parts and materials for machines)
4. Warehousemen and shippers

D. Other overhead

Variable	Fixed
Indirect labor (already mentioned)	Salaried supervisor
Vacation and holiday pay	Clerical
Benefits and taxes	Vacation and holiday
Maintenance Equip. and Building material	Property taxes
	Benefits and taxes
Maintenance--outside services	Utilities
Tooling maintenance	Freight-in

Maint. mat. and outside service boiler	Travel
Operating supplied	Experimental
Utilities	Royalty expense
Outside manpower	Rental of Equipment
	Miscellaneous

7.3 Justification for Selecting a Particular Item to be Examined

While it would be nice for this study to handle each of the items above, both the tremendous number of the various items as well as a time constraint make it necessary to illustrate the proposed management tool on only one particular item. Therefore, although the tool may be applied to most of the items above, only one was selected.

Because of the ready accessibility of data on direct labor items, it was decided that a labor function from either the brush or plastics division would be selected. Since the number of each item manufactured in the brush plant was many times greater than that in the plastics division, it was then decided for purposes of having a large sampling base (so that the central limit theorem could be applied to the sampling distributions) that the labor requirement chosen should be from the brush plant, either stapling or finishing.

In choosing between the two, it was decided to select that labor function for which the reason for a deviation could be more easily marked. It should be repeated here that the one component of the payoff table is "K", the cost of correction. To judge the workability of the proposed technique, it would be advantageous to begin with an item for which management had some indication as to the reasons for potential deviation, and in addition, since it is assumed that the investigation will reveal the cause of the problem, and it will be subsequently corrected, the number of reasons should be as small as possible. Based on talks with the work management coordinator, it was believed that the finishing operation would be the optimum choice.

By scanning the work sheets[3] for different hair brushes in a selected month (December, 1971), it was decided to select the <u>specific</u> labor requirement (under finishing) for which: (1) a large enough sampling base existed, (2) the ability to work with "K" was facilitated, and (3) the figures representing actual performance were somewhat dissimilar. This last prerequisite was inserted so that various brushes could be tested with the possibility of some being "unfavorably out of control." In this way, various possible outputs of the technique could be seen. With each of the above criteria in mind, it was finally decided to select the heat-seal operation as applied to various hair brushes.

In the heat-sealing operation, one operator works a machine which places a plastic bubble covering over the particular brush. After this operation, only the boxing requirement remains. In terms of the various brushes worked on, there are different standards corresponding to different brushes. Of the eleven possible brushes, it was decided to select one category containing three brushes (632, 612, and 3982), all having a present standard of 289 brushes per hour.

Therefore, focusing on these three brushes, attention shall be directed on the question of whether or not deviations from standard should be investigated. It should be repeated that although there is a price and usage standard (see Chapter III), since primary concern in the brush plant is for production, only the usage standard shall be considered.

7.4 Present Control System

Since it is suggested that the proposed decision-making technique be used within the present environment at the organization under study, it is necessary to understand the present control system. Therefore, the scheme used in chapters three through five, that is, discussing the control process in terms of the five components, shall be followed.

7.4.1 Setting of the Labor Usage Standard[4]

Since the workers are not unionized nor do they perform piece work, it is very important that great care go into the setting of the standard. As a first step, the process engineer (1) looks at the specifications for the task (especially if it is a machine-oriented job), and (2) observes for a one-half hour period three samples of the job being performed. Based on his evaluation of the above, he first determines the maximum capability of a trained operator working sixty minutes an hour with no outside interference.

At this point, he discounts the maximum capability level to arrive at a "reasonable expectancy" level. From talks with the work management coordinator, it was noted that this new level represented a somewhat loose standard for which workers could achieve.

Once the standard has been determined, it is sent to the department foreman (supervisor) who must accept or reject it. It is believed that if the supervisor participates at least in this way he can be held more accountable for the particular standard. If the supervisor rejects the standard, then there is arbitration conducted by the plant manager (manager of the brush plant).

Although the agreed upon standard is marked as the 100% performance level, two factors reduce this figure to one which must be met by the workers: (1) a 5% allowance for coffee breaks, and (2) another 5% allowance for any other reason. In effect, a figure representing a 90% performance level becomes the cutoff point for acceptable performance. Any performance below 90% is deemed "out of control"; any above 90% is considered "in control."

It should be noted that since the 100% figure is somewhat loose (it represents average expected performance), it is possible to achieve a performance level above 100%. Nevertheless, in such a case, the system would still be regarded as in control.

In speaking to the work management coordinator, it was learned that although rarely done, standards can be updated. Generally, there are three ways in which this can occur: (1) methods improvement (a better way is learned to complete the task), (2) grading (a different quality of performance is desired to match a competitor, and (3) the standard has been poorly set (determined by judgment and observation).

7.4.2 Collection of the Data

On a given day at the factory, there would be three shifts in which workers could be performing the heat-sealing operation. In order to record the actual results and handle perfromance levels below 90%, a schedule clerk every two hours records the actual performance level on a daily performance report (Figure 13):

Figure 13

Daily Performance Report
At Organization Under Study[5]

Department ________ Supervisor ________ Date ________

Shift _____

Name	Standard	Diff. from Standard	Diff.	Diff.	Diff.	Per-form-ance in min-utes	Min-utes avail-able	% pro-duc-tion
Heat-sealers								
	Units / Minutes							
(Jones)	300 / 120 600 / 120 brush number 632	0	300 120 500 100 20	300 120 600 120 0	300 120 600 120 0	460	480	95.83
(Smith)								
Packing								
Drilling								
Spot Inspection								
Trimming								

Instead of identifying the figures in terms of units per hour, the organization uses a system where each figure is converted to a number of minutes, and therefore deviations are expressed in terms of lost minutes. With the 100% standard expressed simply as 120 earned minutes (in a two-hour check period), actual performance in units is converted to a number of earned minutes according to the following:

$$\text{Earned minutes} = \frac{\text{pieces produced in a two-hour period}}{\text{standard units per hour}} \times 60$$

A comparison of this figure (actual performance expressed in earned minutes) with the standard determines the deviation. In the check period with the ten-minute coffee break, only 110 earned minutes are required.

To illustrate the above, assume the standard to be 300 units per hour (for a two-hour period this would equal 120 minutes). If in the two-hour period 500 units are completed, 100 minutes have been earned. Comparing this figure to the times available (120 minutes), it can be seen that twenty minutes were lost. If this period were a coffee break period, only 110 minutes would be noted, and therefore the deviation would be ten minutes (110 - 100 earned minutes).

7.4.3 Analysis of the Data

If in any two-hour period the actual performance level is below the 90% cutoff figure, the schedule clerk must record on the Action Taken Report (Figure 14): (1) the name of the individual at fault, (2) a reason for the below-par performance, and (3) any corrective action taken.

Figure 14

Action Taken Report
At Organization Under Study[6]

Shift_____

Department_______ Section_______ Date_________

Scheduled period	Name	Scheduled time in minutes	Actual in minutes	Diff.	Reason (A-M)	Corrective action
1 & 2						
3 & 4						
5 & 6						
7 & 8						

7.4.4 Investigation and Correction of Deviations

To obtain the reason for the inadequate performance, the schedule clerk asks the supervisor to mark one of several possible problem areas (lettered A through M; for a complete list of the possible causes, see Appendix B). Beside the designated letter, the schedule clerk marks the corrective action taken by the supervisor.

At the end of each shift, the particular supervisor totals on a summary sheet (Action Taken Recap--Figure 15) the number of minutes lost for performance levels under 90% (of the standard) for each possible reason for the lost time (lettered A through M). Then, the supervisor and his boss (the manager of the brush plant) come together, and the supervisor is held accountable for deviations.

Figure 15

Action Taken Recap
At Organization Under Study[7]

Location__________ Department___________ Date _________

Shift _________

Scheduled
Period A B C D E F G H I J K L M

1
2
3
4
5
6
7
8

Totals 293 298 279

7.5 Implementation of the Proposed Technique

Given the existing control system at the organization, the proposed technique was implemented with the idea that it would be a supplementary device used to highlight problem areas which escaped the regular control process. Therefore, so that the data for the two months under study could be assumed to have resulted with such a device in use, adherence was made to the existing guidelines established by the organization (setting control limits, having two-hour checks on performance, etc.).

7.5.1 <u>The Standard</u>

Recalling from the previous chapter that the first task is to make an initial estimate as to expected average performance and to designate the mean of that distribution as the standard, an identical questionnaire (found in Appendix A) was administered to: (1) the supervisor in charge of the heat-sealing operation, and (2) a process engineer familiar with the operation.

It should be repeated here that the heat-sealing operation is done on various categories of brushes for which different standards apply to the different categories. Therefore, although only one category was selected, it was necessary to identify on the questionnaire the brush number to which a performance level was related.

In any case, since a maximum performance level serves well as a reference point, the first question asked for the estimated average heat-sealing performance level (on brushes 632, 612, and 3982) under ideal conditions (100 percent efficiency). Interestingly enough, the engineer's reply of 320 units per hour (for each brush) was ten units less than the 330 figure suggested by the supervisor.

Since the anlayst using this technique is interested in an <u>average</u> expected (average) performance level, the ideal figure (100 percent) must be discounted (for possible breakdowns, inefficiencies, etc.). A 10 percent factor was used as the discount figure, because it was believed by the engineer and supervisor that 90 percent of the ideal would represent average performance. Therefore, computing the 90 percent figures, the engineer's estimate becomes the present standard of 288 units per hour(.9 x 320), and the supervisor's estimate becomes 297 units per hour (.9 x 330).

While these two figures 288 and 297, can be considered as grand means of two sampling distributions (imagine that the engineer and supervisor had sampled these results), it is still necessary to compute the standard deviation of the two sampling distributions. These figures in effect represent the respective individual's confidence in the grand mean figures.

To obtain a reasonable determination of the respective standard deviations, the engineer and supervisor were posed with the following question:

> Because there exists the possibility of adverse or favorable conditions, for a given average worker, there will be fluctuations in the number of brushes heat-sealed per hour above and below the average performance of the average worker. Around this figure (average performance), indicate a range within which you are reasonably sure an average worker will perform 50% of the time.
>
> Answer: 50% of the time the average worker should heat-seal within_____brushes per hour on either side of the average performance level.

The replies were 16 (by the engineer) and 10 (by the supervisor).

To convert the 16 and 10 replies to the appropriate standard deviation figures, it should be remembered that because of the central limit theorem (it is assumed that the engineer and supervisor had taken a large number of samples in arriving at the 288 and 297 figures) the distributions approximate normal distributions. Therefore, since their replies are intended to reflect 50 percent of the area under the curve (corresponding to two-thirds of a standard deviation on either side of the mean), to compute the respective standard deviations, the 16 and 10 figures must each be divided by 2/3:

Standard deviation (engineer) = 16/(2/3) = $\underline{\underline{24}}$

Standard deviation (supervisor = 16/(2/3) = $\underline{\underline{15}}$

Given the two estimates of average expected performance, normal conjugate theory can be used to combine the two. Therefore, referring to section 6.2.3, the following calculations were made:

where $\mu_0 = 288$ $\qquad \bar{\bar{x}} = 297$

$\sigma_0 = 24$ $\qquad \sigma(\bar{x}) = 15$

$$\mu_1 = \frac{288/(24)^2 + 297/(15)^2}{1/(24)^2 + 1/(15)^2} = \underline{\underline{295}}$$

$$1/\sigma_1^2 = 1/(24)^2 + 1/(15)^2 = .00618$$

$$\sigma_1 = 1/\sqrt{.00618} = \underline{\underline{12.7}}$$

In analyzing the above data, it should be repeated that μ_1 represents the combination of two sampling distributions.

Notice that the 295 figure is closer to the 297 figure given by the supervisor, since it is assumed that the supervisor had used a larger sample ot obtain the 297 figure (because of the smaller standard deviation, 15 versus 24). The updated standard deviation (12.7) is lower than either the 24 or 15 figures, since the combination of the two sampling distributions brings more information than either one separately.

In equating the standard to this 295 figure, the additional participation by the supervisor (actually involved in the standard-setting rather than merely in its acceptance or rejection) should aid in the long-run in bringing about the understandability and acceptance of the technique by the supervisor. It is interesting to note that in this example the 297 estimate by the supervisor caused a higher standard than would have been determined by the engineer's estimate alone.

7.5.2 Control limits

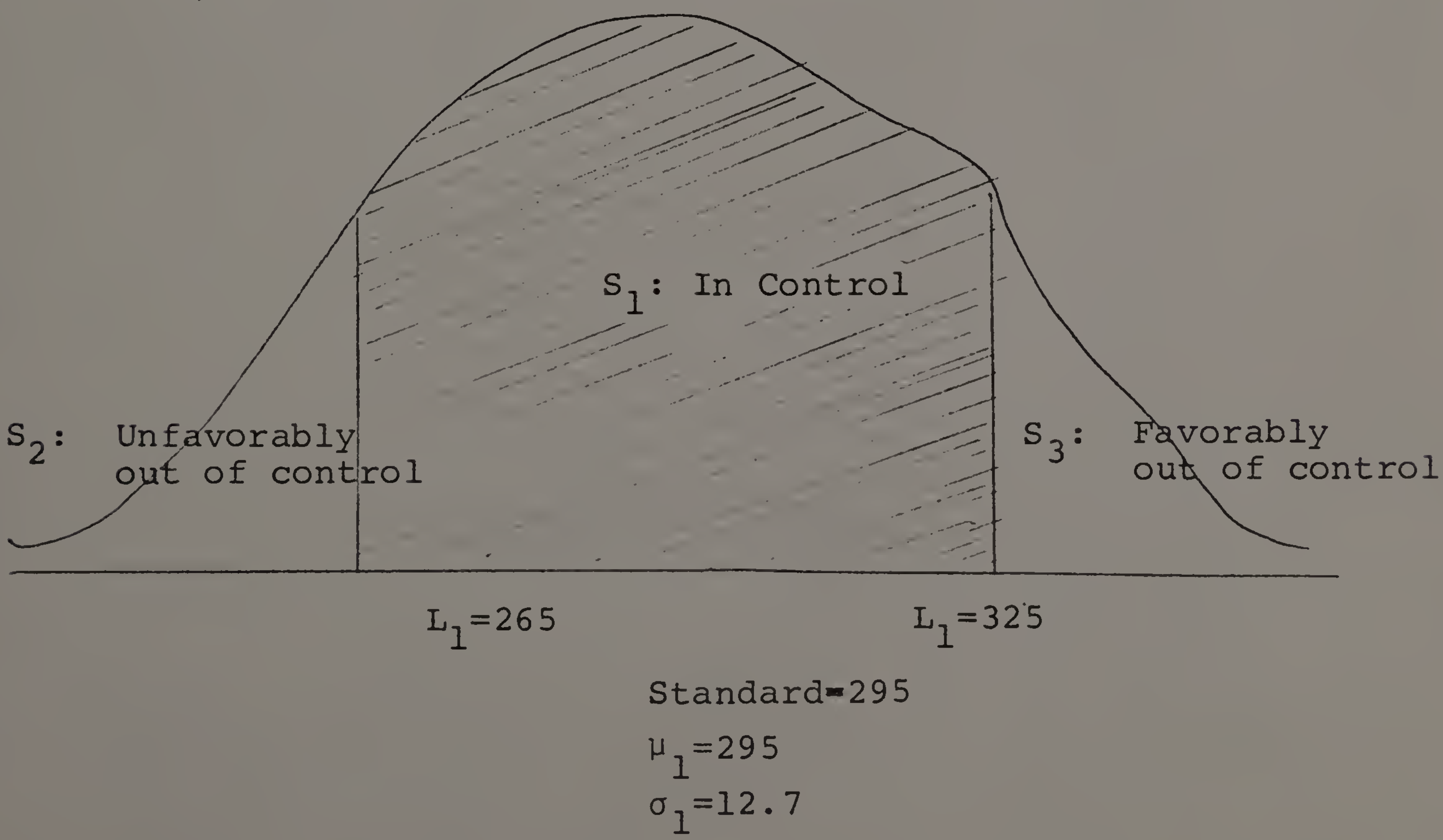
With the standard set, it was necessary to identify the three regions known as "in control,""unfavorably out of control," and "favorably out of control." To do so, attention must be directed towards selecting an allowance factor on either side of the standard which forms the "in control" region. Having determined from this factor both the upper and lower control limits, the three states of nature can be derived.

In determining the allowance factor, the company under study now employes a 10% discount on the standard, 5% of which is supposed to be explained by coffee breaks (ten minutes are allowed every two hours) and the other 5% allowed for miscellaneous reasons. Based on this figure, if true performance lies below 90% of the standard, the system is deemed "unfavorably out of control." Using the same 10% figure to determine the upper control limit, performance above 110% is ruled "favorably out of control." Between the control limits is the "in control" region.

Applying these figures to the standard of 295 units per hour, the following figure depicts the control chart for the 632, 612, and 3982 hair brushes:

Figure 16

Control Chart for Brushes 632, 612, 3982



where $L_1 = .9 \times 295 = 265$ (Rounded off)

$L_2 = 1.1 \times 295 = 325$

7.5.3 Prior Information

Since the distribution representing expected average performance was formulated by the engineer and supervisor in order to determine the standard (the mean of the distribution offers initial evidence as to the true state of nature. For this reason, the subjective "initial posterior distribution" with mean at 295 and standard deviation at 12.7 becomes the prior for the first month.

Because the above estimate does not consider the five percent allowance for coffee breaks (and it is believed that workers will take full advantage of this allotted time), an adjusted estimate of expected average performance would include a five percent discount of each number in the original distribution. Therefore, this adjusted prior distribution reflecting what the engineer and supervisor believe the true state of nature to be has a mean of 280 (.95 x 295) and a standard deviation of 12.065 (.95 x 12.7).

7.5.4 The Payoff Table

Given the possible states of nature (S_1, S_2, and S_3), there are various costs which will occur depending upon which of two acts is undertaken: investigate and not investigate. Therefore, referring to the payoff table (Table 10--Chapter VI) which gives a literal representation of the cost involved, it will be necessary to quantify (in addition to the items already determined: (A) cost of investigation, (B) time spent on investigation, (C) cost of correction, (D) time spent on correction, (E) opportunity loss per unit, and (F) hours in the period.

Although this quantification appeared simple enough, it was very difficult to determine these figures, because the organization under study had previously not considered these costs in this decision-making context. Under the present investigation scheme, the decision-rule had been to investigate any deviation greater than 10%, otherwise not. No effort had been made to consider the various costs for each act.

Nevertheless, through extensive discussion with the work management coordinator and in addition the feedback from his work with process engineers, the supervisor for the heat-sealing operation, and plant records, the following was determined:

A. Cost of investigation (C)

It was believed that to investigate adequately a deviation to determine a possible problem area, it would take: (1) clerical research through five days records (consisting of examining the daily performance reports, the action taken reports, and the action taken recap reports) at twenty minutes per day, and (2) an engineering investigation for possibility of non-optimum work technique, possible trouble with the machine, or perhaps the need to change the standard.

The cost value would be the total cost for the clerical research and engineering study:

Clerical research cost = (1/3 hour per day) x (5 days) x ($4.50 labor and overhead)

= $7.43

Engineering cost = 1.0 hour x $7.00 wages

= $7.00

Total cost = $7.43 + $7.00

= $14.43

B. Time spent on investigation (m_1)

If in the process of making the investigation, some time is taken away from the workers in performing their task, this time must be reflected in the payoff table. While the clerical research need not bother the workers, it is possible for part of the engineering investigation to stop work. Therefore, estimating that of the one hour time period spent on the investigation by the engineer, half results in the loss of work, the lost time equals .5 hours.

C. Cost of correction (K)

To quantify this item, it was first necessary to determine how the total number of lost minutes in the heat-sealing operation were spread out amongst the various possible problem areas (lettered A-M). Having this distribution available (obtained by summing the figures of the action taken recap report), it was possible to estimate the most likely problem areas.

As a result, of the total lost-time, it was estimated that 56 percent can be attributed to efficiency problems and 44 percent to other reasons, a major portion of which comprises mechanical/electrical machine malfunction.

In terms of the efficiency problem, the following table lists the major possible courses of action, the estimated cost of each program, and the estimated probability of their occurrence:

Table 14

Efficiency Problems
At Organization Under Study

Course of Action	Cost	Probability
Termination and replacement of workers	$200	.2
Retraining (because of non-optimal work) technique	50	.3
Supervisory council	20	.5

Combining these figures, it can be reasoned that the expected correction for efficiency problems is:

$$\text{Expected efficiency correction cost} = (.2 \times \$200) + (.3 \times \$50) + (.5 \times \$20) = \$65$$

To determine the correction cost for other problem areas (mechanical/electrical, etc.), it was concluded (through talks between the work management coordinator and the process engineers) that the following must be considered:

Correction time cost = 2 hrs. x \$4.50 = \$9.00

Materials cost = \$21

Expected mechanical/electrical cost = \$30

By combining the two costs, the \$65 efficiency problem cost and the \$30 other problems cost, with the respective probability assessments for their occurrence (.56 and .44), it can be reasoned that the expected correction cost is:

Expected correction cost = (.56 x \$65) + (.44 x \$30)

= \$49.60

It should be noted that the determination of the cost of correction depends heavily on the probability assessments. Although it was intended that these figures be long-run estimates, it is still possible that they change in a subsequent period. If that happens, then the probabilities should be reassessed and the calculations recomputed.

In setting up the payoff table, it was assumed that for the state of nature marked "unfavorably out of control," the decision to investigate would also demand the correction of the problem area (determined from the investigation). That is the procedure taken now at the organization under study, since corrections are made once an investigation has been taken (action taken report). It should be pointed out that if the investigation revealed the need to change the standard itself, the entire process would begin again (set standard, establish prior, etc.).

D. Time spent on correction (m_2)

To gauge the time taken away from production because of correction of the problem necessitates estimating various times relating to the possible problem areas and computing an expected time away from production. Therefore, applying the figures from Table 15:

Table 15

Estimated Times for Corrective Action
At Organization Under Study

Courses of Action		Estimated Time (In Hours)
Efficiency:	Termination	0.0
	Demonstration as to correct work technique	.5
	Supervisory council	1.0
Other (Mechanical/Electrical)		2.0

Expected time (efficiency problems) = (.2 x 0) + (.3 x .5)
+ (.5 x 1)
= .65 hours

Expected time (other problems) = 2 hours

Total expected time = (.56 x 65 hours) + (.44 x 2 hours)
≅ 1.25 hours

Total time taken away from production (m_3)

This is simply the sum of m_1 and m_2:

m_3 = .5 hours + 1.25 hours = 1.75 hours

E. Opportunity loss per unit (P)

At the organization under study, it was learned that operations after the heat-sealing operation are performed regardless of whether units come from the heat-sealing operation (if one brush is not ready, another one will be worked on). Stapled brushes (complete up to heat-sealing) are sold in other packs and in theory can be salvaged from heat seal losses. Therefore, the opportunity loss involves only the cost of heat-sealing.

From the accounting records, it was determined that the cost per hour for direct labor and benefits is $4.09. As a result, based on a long-run estimate of 288 units per hour as the normal production level (determined by the engineer), the cost per unit which must be absorbed is $4.09 divided by 288 units, namely $.0142 per unit.

F. Hours of production for a given brush (H)

If slightly over a penny is lost for every unit per hour undone, the total loss will be the $.0142 multiplied by the number of hours which will be worked on a given brush per period (a month). Although work on each brush number is continuous throughout the month, it should be pointed out that there can be a different number of workers heat-sealing a certain brush each shift, and this can be applied to the three possible shifts.

To compute the total number of hours worked on each brush per month, it is necessary first to indicate how many hours per day are worked on each. Therefore, as noted in Table 16, it is estimated that on the average three workers are assigned to brush 632, two workers for brush 3982, and only one for brush 612. With eight hour shifts, it can be concluded that per day a total of 24 hours are spent on 632, 16 hours on 3982, and 8 hours on 612. Estimating the working days in the month at 20, it can be finally determined that in total 480 hours are spent on 632, 320 hours on 3982, and 160 hours on 612.

Table 16

Total Hours Worked On Each Brush

Brush No.	Shift 1	Shift 2	Shift 3	Total	Hours worked per day-- 8-hour shifts	Total hours per period-- 20 working days per month
632	2	1	0	3	24	480
3982	1	1	0	2	16	320
612	1	0	0	1	8	160

With all the figures quantified, it is now possible to assemble the payoff table. Therefore, using the standard of 295 with 10% control limits, note the following table which represents the costs to the organization under study given the two possible acts (investigate, not investigate) and the three states of nature (in control, unfavorable, favorable):

Table 17

Payoff Table
Heat-Sealing Operation

	S_2: Unfavorable	S_1: In Control	S_3: Favorable
A_1: Inv.	$14.43 + 49.60$ $+.0142(\mu_x)(1.75)$	14.43 $+.0142(u_x)(.5)$	14.43 $+.0142(\mu_x)(.5)$ $-.0142(\mu_x-325)(H)$
A_2: No inv.	$.0142(\mu_x)(265-\mu_x)(H)$	0.0	$-.0142(\mu_x-325(H)$

where $C = 14.43$ μ_x = true state of nature

$K = 49.60$ $L_1 = 265$

$P = .0142$ $L_2 = 325$

$m_1 = .5$ H = 480 for 632 brush
320 for 3982 brush
160 for 612 brush

$m_2 = 1.25$

$m_3 = 1.75$

$$\text{and } C(A_1,\mu_x)=\begin{cases} 14.43+49.60+.0142(\mu_x)174 & \mu_x<265 \\ 14.43+.0142(.5)\mu_x & \text{if } 265\leq {}_x\leq 325 \\ 14.43+.0142(.5)\mu_x-.0142(H)(u_x-325 & \mu_x>325 \end{cases}$$

$$C(A_2,\mu_x) = \begin{cases} .0142(H)(265-\mu_x) & \mu_x<265 \\ 0 & \text{if } 265\leq {}_x\leq 325 \\ -.0142(H)(\mu_x-325) & \mu_x>325 \end{cases}$$

where $C(A_x,\mu_x)$ is a random variable, since μ_x is a random variable according to $N(\mu_1,\sigma_1)$.

7.5.5 Initial Expected Costs

Before determining whether the prior information should be updated, it would be interesting to consider the initial expected costs. It should be pointed out that in the month in which the standard of 295 was set and in any month following an investigation and correction (bringing the system back into control), the resulting figures would be the same as shall be calculated below. Once determined, these two figures are compared to each other with the decision-rule being to select that act with the lowest expected cost.

Therefore, using the EXPT computer program to combine N(280, 12.065) with the payoff table above (Table 17), the following was determined:

Brush 632 (H=480 hours)

EC(Inv.) = 23.09
EC(No inv.) = 5.00

Brush 3982 (H=320 hours)

EC(Inv.) = 23.09
EC(No inv.) = 3.33

Brush 612 (H=160 hours)

EC(Inv.) = 23.09
EC(No inv.) = 1.67

From the above information it can be seen that given the initial prior distribution (μ_1=280 and σ_1=12.065) in all three cases the optimum decision *initially* is not to investigate. However, because, as the value for "H" becomes greater, the slope of the cost function for not investigating also becomes greater. For this reason, with brush 632 (H=480), expected cost for not investigating is \$5.00. With brush 612 (H=160), the expected cost is only \$1.67.

7.5.6 Additional Information

Although the prior distribution has been determined and initial expected costs calculated, it is still necessary to consider the effect of this month's actual performance. Therefore, either by using all the data available or by randomly sampling from it, the analyst will update the prior distribution and recalculate expected costs.

In determining the optimum sample size, it is believed that because of the moderate sample cost as well as the computer cost needed to compute various EVSI levels, it is advantageous to use the maximum number of samples each month for each brush.

Before giving proof as to this point, it is necessary to define a particular sample. Because the Daily Performance Report records performance every two hours, it is believed that the analyst should use a worker's average performance per two-hour check as sample size of one. Given the number of hours worked on a particular brush per month, it is possible to compute the maximum sample sizes:

Brush 632:	480 hours/2 hour check =	240
Brush 3982:	320 hours/2 hour check =	160
Brush 612:	160 hours/2 hour check =	80

Since the performance for all three brushes per shift is on the same sheet, a schedule clerk determining the sample means per brush could use a form similar to Figure 17:

Figure 17

Recording Sample Means
Suggested Form

Date____________ Shift no.____

	Brush Number		
Worker's name	632	3982	612
(Jones)	280		
(Smith)	275		
(Carson)		265	
(Riley)			220

Estimating that it takes, using a calculator, at the most one minute to record a maximum of four sample means per sheet (see Table 16), with three sheets per day and twenty working days per month, the total amount of time to record all the sample means for all three brushes should be approximately one hour. At $4.50 labor and overhead cost associated with the schedule clerk's time, the maximum it should cost is 1 hr. x $4.50 = $4.50.

If the maximum number is not used, but instead randomly selected samples are taken (for the "optimum" number of samples) two events occur. First, there is some time and effort taken to: (1) list the appropriate random numbers, and (2) link the random numbers to the appropriate Daily Performance Sheet. In addition, once the sheet has been pulled by the schedule clerk, the incremental time per sample mean calculation is quite small. Therefore, it is doubted whether reducing the number of samples can substantially reduce the \$4.50 figure.

Besides this failure to reduce the \$4.50 by random sampling, the computer cost for calculating various EVSI values would more than substitute for any saved time. At \$50 an hour for sign-on time at the organization under study,[8] each minute on the terminal represents \$.83^{+}.

Based on this computer cost as well as the relatively small \$4.50 all-inconclusive sampling cost, it was concluded that the maximum number of samples should be used. Therefore, using a computer program to calculate the sampling mean and standard error for each sampling distribution (for each brush), it should take at the most five minutes per run (to type in the numbers). At \$50 per hour computer cost, the total expense would be 15/60 x \$50 = \$12.50.

If the total EVPI for all three brushes exceeds \$16.00 (\$4.50 clerical cost plus \$12.50 computer cost), then the entire sampling is well worth the cost. Since previous months' sampling distributions are necessary as the prior for a particular month, in any period where the EVPI is below the cost of sampling, that difference should be considered a cost for employing the proposed technique.[9] In the next chapter, consideration shall be directed toward these implementation costs.

7.5.7 The Terminal Decision

In order to demonstrate various outcomes of the technique, the application will be directed to the heat-seal operation on the three brushes (632, 3982, and 612) for a two month period, December, 1971 to January, 1972. The focus shall be on the terminal decision as to whether an investigation should be undertaken on any of the brushes.

December, 1971

Although the total cost of sampling is only $16.00 and it has already been determined that it is less costly to formulate the entire sampling distribution than to calculate various EVSI's, it would prove beneficial to determine the cutoff point (where one is indifferent as to the optimum act to choose) and based on this point the EVPI. In this way, it will be possible to obtain some idea as to what kind of sampling distribution will be necessary in the given month to alter the effect of the prior information.

Therefore, using the EXPT computer program, both the cutoff point and EVPI were determined for each brush:

Brush 632 (H=480)

Cutoff point = $PHL_1 - C - K/(Pm_3 + PH)$

$$= \frac{(.0142)(480)(265)-(14.43)-(49.60)}{.0142(1.75) \quad + \quad (.0142)(480)} = 255.67$$

EVPI equals expected loss of the optimum act given the prior estimate of μ_x. Since μ_1=280, A_2 is optimum and thus:

$$EVPI = EL(A_2) = \int_{-\infty}^{T} [(PHL_1 - C - K) - (PH + Pm_3)(w)]\ f(w)dw$$

$$= \int_{-\infty}^{255.67} [(.0142)(480)(265)-14.43-49.60)$$

$$- (.0142(480)-.0142(1.75)w)]f(w)dw$$

$$= \underline{\underline{\$.70}}$$

Several points deserve mentioning. First, although 265 units is the lower control limit, the true state of nature must be below 255.67 units before an investigation is optimum. Based on the prior estimate of 280 as the true state of nature (with precision determined by standard deviation of 12.065), the analyst should pay no more than $.70 for additional information.

It should be repeated that the further away the prior mean is from the cutoff and the smaller the standard deviation (higher precision), the smaller the EVPI and therefore the smaller the affect of the sampling distribution on the prior.

Brush 3982 (H=320)

Cutoff point = 250.53

EVPI = $.13

Because the number of hours worked on this brush is less than on the popular 632 brush, the true state of nature must be further away from the lower control limit of 265 units per hour before investigating is the optimum act. This accounts for the lower cutoff point (250.53 versus 255.67 for brush 632). In addition, since the prior mean is now further away from the cutoff point, the EVPI is smaller $.13 versus $.70).

The effect of the sampling distribution on the investigation decision this month is less than with the 632 brush.

Brush 612 (H=160)

Cutoff point = 235.24

EVPI = \$0.00

Since only 160 hours will be applied to this brush, productivity must be especially low to warrant an investigation. With an EVPI of zero, in effect the sampling distribution of the current month has no effect on the decision.

By considering a sample as the average performance per worker per two-hour check period, for the month of December the following represents the sampling distributions for each brush (sampling mean and standard distribution):

Brush 632 (H=480)[10]

$\bar{x}$ = 274.57 (rounded to two places)

$\sigma(\bar{x})$ = 22.18

Brush 3982 (H=320)

$\bar{x}$ = 285.64

$\sigma(\bar{x})$ = 28.50

Brush 612 (H=160)

$\bar{x}$ = 212.94

$\sigma(\bar{x})$ = 29.06

Using the EXPT computer program, it is now possible to read in both the prior distribution and the sampling distributions to arrive at: (1) the posterior mean, (2) the posterior standard deviation, and (3) expected costs for the two acts. Therefore, applying the program on each of the three brushes, the following was determined:

<u>Brush 632</u>

$$\mu_2 = \frac{280/12.065 + 274.57/22.18}{1/12.065 + 1/22.18} = \underline{\underline{278.76}}$$

$$1/\sigma_2^2 = 1/12.065 + 1/22.18 = .0089$$

$$\sigma_2 = 1/\sqrt{.0089} = \underline{\underline{10.60}}$$

$$EC(A_1,\mu_x) = \int_{-\infty}^{265}[14.43 + 49.60 + .0142(1.75)w]f(w)dw$$

$$+ \int_{265}^{325}[14.43 + .0142(.5)w]f(w)dw$$

$$+ \int_{325}^{\infty}[14.43 + .0142(.5)w - .0142(480)(w-325)]f(w)dw$$

$$= \underline{\underline{22.65}}$$

$$EC(A_2,\mu_x) = \int_{-\infty}^{265}.0142(480)(265-w)f(w)dw$$

$$+ \int_{325}^{\infty} -.0142(480(w-325)f(w)dw$$

$$= \underline{\underline{3.95}}$$

Because of the higher precision of the 280 prior sampling mean (12.065 versus 22.18), the posterior mean is closer to the prior mean (both are well in control). Since the posterior estimate of 278.76 is well within the control limits, and the posterior standard deviation is small enough, it is optimum not to investigate brush 632.

Brush 3982 (H=320)

$\mu_2 = 280.86$

$\sigma_2 = 11.11$

EC(Inv.) = 21.30

EC(No inv.) = 2.15

Since brush 3982 has a slightly higher mean than brush 632 (280.86 versus 278.76), and since the value for "H" is lower (causing a flatter loss function for not investigating), one would expect for the 3982 brush a lower expected cost for no investigation (2.15 versus 3.95). With this brush, the optimum act is not to investigate.

Brush 612 (H=160)

$\mu_2 = 270.14$

$\sigma_2 = 11.14$

EC(inv.) = 35.62

EC(No inv.) = 6.08

Although the sampling mean of 212.94 brought the prior estimate slightly downward to 270.14, the degree of change was slight because of the tremendous difference in precision with standard deviations of 12.065 and 29.06 respectively. Although the 270.14 figure is close to the lower control limit (265), it is well above the cutoff point for this brush of 235.24. Based on this information, the optimum act is still not to investigate.

A second significant factor was the prior distribution. Because it was the first month and the 280 figure was used, with such a low cutoff point (234.35), the 212.94 sampling mean had little effect on the decision (EVPI=0). However, since no investigation was taken, that figure will now be used as the prior estimate for January. If January's performance is relatively good, then no investigation will be necessary for that month. (It will be concluded that December's performance was not representative of the process.) If, on the other hand, January's performance is also poor, then the investigation will be taken at that point.

January 1972

For January, the following sampling distributions were determined:

Brush 632 (H=480)

$\bar{x} = 283.96$

$\sigma(\bar{x}) = 3.98$

Brush 3982 (H=320)

$\bar{x} = 289.10$

$\sigma(\bar{x}) = 20.24$

Brush 612 (H=160)

$\bar{x} = 200.59$

$\sigma(\bar{x}) = 32.02$

Since no investigations were taken in December, the December sampling distributions become the prior for January. Again, using the computer program, posterior distributions were formulated and expected costs calculated:

Brush 632

$\mu_2 = 281.29$

$\sigma_2 = 11.82$

EC (Inv.) = 21.76

EC (No inv.) = 3.67

Here again the average performance estimated at 281.29 is well within the control limits. With confidence that this figure represents the true state of nature (posterior standard deviation of 11.82, the optimum act is not to investigate.

Brush 3982

$\mu_2 = 287.94$

$\sigma_2 = 16.50$

EV (Inv.) = 21.10

EC (No inv.) = 2.86

Performance on this brush seems to be remarkable, since on the average workers are performing over seven units per hour higher than the subjective prior of 280 (295 standard less 5% coffee break). Needless to say, no investigation is necessary.

Brush 612

$\mu_2 = 207.36$

$\sigma_2 = 21.52$

EC (Inv.) = 69.00

EC (No inv.) = 133.26

While the original prior prohibited an investigation in December, the results in January clearly indicate that an investigation is necessary on brush 612. What is worth repeating is that although only 160 hours worth of work is done on brush 612 per month, performance is so low that the problem area is worth searching for. It is well worth noting that even within the tight control system at this organization an additional investigation is required.

With the investigation taken, the problem area identified, and the corrective action pursued, the system should fall back into control. Therefore, as long as the standard is not changed, the prior distribution for February for brush 612 is the subjective prior of $\mu_1=280$ and $\sigma_1=12.065$. If the standard is changed, the entire process starts again. In terms of the other two brushes (632 and 3982), their prior distributions for February would be the January sampling distributions.

FOOTNOTES

1. In order to assure anonymity for the organization under study, no mention is made of either the name of the company or any of its employees.

2. This information was obtained through interviews with the work management coordinator of the New England plant, an individual who heads the entire work scheduling operation.

3. These work sheets (called Daily Performance Reports) indicate the actual performance for the finishing operation of hair brushes.

4. This information was obtained through interviews with the work management coordinator.

5. This was taken from the accounting records at the organization.

6. <u>Ibid</u>.

7. <u>Ibid</u>.

8. This figure was obtained from the head of the computer operations.

9. It is believed that EVSI for the maximum number of samples will approximate EVPI.

10. The individual samples were obtained from the Daily Performance Reports. Using a computer program, the estimate of the population mean was determined according to:

$$\bar{\bar{x}} = \Sigma x_i / n$$

The standard deviation of the sampling distribution was determined according to:

$$\sigma(\bar{\bar{x}}) = \sqrt{\Sigma(x_i - \bar{\bar{x}})^2/(n-1)} \Big/ \sqrt{n}$$

For a complete analysis of the above, see Appendix D.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

8.1 Introduction

From the beginning of this study, the central issue has been the desire to achieve an effective control system, that is, to provide the necessary mechanisms which can influence the organization's members to perform according to the adopted plans, issued instructions, and established principles. The intent of this research has been to suggest an additional mechanism which can be used to better the existing control techniques. In this chapter, discussion shall relate to: (1) a review of the basis for the proposed management tool, (2) a judgment as to the effectiveness of the model, (3) the application of the took, and (4) suggestions for future research.

8.2 Basis for the Management Tool

In this section, a brief summary shall be made of the context within which the proposed management tool was suggested. The intent is to review the background for the tool as well as to recreate the necessity for such an item.

Initially, attention was directed toward the rationale used in selecting the particular topic under study. Specifically, a case was made for the importance of the control process within an organization and the necessity for seeking new control techniques.

After defining control as the process by which one element intentionally affects the actions of another element, Hofstede noted that the control process served as the fundamental organizational link between the manager and other people. The objective of this link, as Fayol pointed out, was to be concerned with future operations such that the control process would be used to take steps in the present in order to avoid problem areas in the future.

In order to achieve this control, the organization had to: (1) establish plans, (2) appraise performance, and (3) correct deviations from the plan. If future actual performance corresponded to the established plans, then the control system was successful. If not, additional costs would be incurred.

While most organizations believe they have assembled an adequate control system, it was learned that the organization under study lacked many of the necessary characteristics of an effective control system (as described by Koontz and O'Donnell). Seeking to control the usage of raw material, it was shown how deviations from standard fluctuated tremendously from month to month. With direct labor, the control was tighter and the results more encouraging, yet it was still believed that the organization could do even better.

Amidst this background, this research study was undertaken in order to establish a decision-theory model which would facilitate answering the question as to whether deviations from standard should be investigated. Before presenting the technique and its test for workability in the real world, an in-depth analysis was made of each aspect of the control process. In doing so, the impact of each component as well as the interrelationships involved were noted in terms of the proposed management tool.

As a first step (Chapter II), a brief historical overview was included to indicate how the events of the past produced an importance for the elements of the control process. From these events, the following process emerged: (1) setting the standard, (2) collecting the actual performance data, (3) analyzing the data, (4) investigating deviations, and (5) correcting deviations. The next three chapters would detail the above process.

Chapter III was concerned with the first aspect of the control process: setting the standard. To start, the terms budgets and standards were identified, and their relationship to the manufacturing process was made known. Secondly, a discussion was made into the tightness and looseness of standards with the suggestion by Langier on one hand and Stedry and Kay on the other that the standard neither be too tight (causing bitterness and dissatisfaction) nor that it be too loose (causing lower productivity). Next, several techniques (including performance rating, stop-watch technique, work sampling, and standard data work measurement systems) were presented to show mechanically how the engineer would set the standard.

Because the standard does represent the cornerstone of the entire control process, it was necessary to discuss the behavioral influences which could bring about the success of the standard (its acceptance) as well as the success of any control technique used at the organization. For this reason, plus the fact that the supervisor could initially find this technique difficult to understand (he might not be knowledgable in statistics and quantitative methods), a case was made for the supervisor participating in the standard-setting.

With the standard set, the next phase of the control process is to collect data and then analyze it. It was shown in Chapter IV that collecting the data involves establishing responsibility areas of concern and secondly making sure the information is objective, timely, and clear. Once the data is reported, the analyzing process involves calculating the deviations (both price and quantity) for each manufacturing element of cost (direct material, direct labor, and overhead).

Any real success in the control process rests not in the results of the past, but in the action taken to assure optimum results in the future. Therefore, in the last two, closely related phases of the control process, investigation and correction, the goal is to determine problem areas as quickly as possible so that they will not occur in the future.

Chapter V provided a discussion of the various techniques already available to handle the investigation decision.

Generally, most organizations employ a traditional approach, where after setting the standard (a point estimate), a deviation from standard is investigated if: (1) the absolute size of a deviation is large, or (2) the relative size of a deviation is large. The decision as to what is large, absolutely or relatively, is based on management's judgment.

A control model based on classical statistics views desired performance as a range estimate, that is, it allows performance to lie within a given number of standard deviation points from the established standard (in this region the system is deemed "in control"). The investigation decision is simply based upon whether the deviation falls outside the control limits. To exercise control, it is assumed that: (1) the distribution of cost is a normal distribution with mean and standard deviation known, (2) the allowable deviations (one, two, or three) have been selected properly, and (3) past conditions of production will remain the same in the future.

Decision models (Bierman, Alderson and Green, and Dyckman) have gone one step further, as they have introduced the payoff table which gives a quantification of the costs involved with making a correct or incorrect decision (cost of investigation versus loss from no investigation). Designating the states of nature as "in control" and "out of control" (determined by the control limits established with classical statistics), the actual results are used to make probability assessments as to these states of nature. Coupling the two probabilities with the payoff table results in two expected cost figures, the lower of which determines which act is optimum (investigate or not investigate).

One other influence into the state of the art has been Bayesian statistics (Hirschleifer, Onsi) which allows the analyst to sample additional data (from the actual results) to use in assessing probabilities for the two states of nature. In deciding the optimum sample size, the sampling cost is balanced against the gains in terms of reduction in the risk of error.

8.3 Effectiveness of the Model

Based on the decision-theory articles and the Bayesian influence, the proposed technique was created. To judge its effectiveness, it is necessary to point out the various features which are absent from other models:

A. Uniqueness in setting of the standard

Because of the behavior necessity for including the supervisor in the standard-setting as well as obtaining as much information as possible as the true state of nature, both the engineer and supervisor were asked to estimate average expected performance by the average worker. Their beliefs treated as sampling distributions were combined using normal conjugate theory to: (1) establish the standard, and

(2) create the prior distribution from the first month.

B. A better conceptual view as to the true state of nature

Much discussion throughout this research study has also centered on the necessity of the control process to influence the future. In other words, it has been shown that the focus of a control system is to handle deviations in the present only to prevent them from occurring at a later point. In previous models, it appears that the point of concern has been merely the present. It was assumed that the situation would always be the same in the future.

In this model, the analyst is also interested in the current data but only in a broader sense that it along with past data will be indicators of expected performance. The real focus, here, is on predicting the future environment. For this reason, both current and past, both objective and subjective evidence was assembled in order to make this prediction.

C. A Subjective Prior

Up to this point, there has been no formal consideration as to the inclusion of a subjective prior. Here, it is suggested that the engineer and supervisor can offer much evidence as to the true state of nature. As a result, by treating their beliefs as sampling distributions and combining them with the objective data from the records, it is believed that the analyst has come closer to "zeroing in" on the true state of nature.

D. Treatment of the state of nature marked "favorably out of control"

Because the established standard was not tight, it was believed that performance above the upper control limit was entirely possible. In addition, when performance does lie in this region, it is believed that the organization receives a gain equal to the additional performance. By including this category within the model, the analyst considers more of the various alternative states of nature.

E. An extensive analysis of the Payoff Table

From the literature, any discussion of the payoff table previously involved a casual attitude as to the costs involved given the possible states of nature. Most models merely produced literal figures to correspond to these costs. Others arbitrarily selected values for these letters. One effort of this model has been to carefully consider each cost, what assumptions should be made, and how difficult would it be to obtain a valuation. In addition, since it was believed that each cell had to be broken down into various components, it was necessary to consider the make-up of each item.

F. Quick results

Finally, because of the computerization of: (1) the combination of sampling distributions, (2) the determination of expected costs, and (3) the calculation of EVPI and various

EVSI's, it is possible to choose the optimum act in a short period of time. In a real situation, with this technique employed with a large number of items (including material, labor, and overhead items), the necessity for computerization is clear.

8.4 Application of the Tool

With the theoretical framework having been formulated and its effectiveness noted, an additional insight as to its worth rests in its operationalization in a real organization. In judging the significance of this aspect of the research, discussion shall relate to the following questions: (1) what contribution does this proposed tool make to the organization under study? and (2) what costs would be incurred in implementing such a system?

8.4.1 Contribution to the Organization

Besides the benefits mentioned above, it is believed that the real contribution of the technique is the way in which it forces the analyst to consider more rigorously the various steps taken in the decision-making process as to the investigation decision. At the organization under study, this was apparent when it came time to quantify the payoff table.

As the work management coordinator was discussing the cost of investigation, he replied that previously it was not customary to think in terms of these expected costs. Indeed, the actual practice had been to investigate any deviation in a two-hour check period greater than ten percent of the standard. If the analyst is directed toward these costs (if he marks the cost of investigation, the cost of correction, and losses for no investigation), then he has a better basis for making his decision.

Because it was impossible to find an organization where the data would be the result solely of this technique, it was believed that in the organization under study the application should be treated as a supplementary device to the existing control system. In doing so, the intent was to work as much as possible within the framework of the existing constraints. As a result, a second contribution is the ability to discover additional problem areas which have escaped the regular process.

As an illustration of the above, consider the supplementary device as applied to Brush 612 which was out of control in both months and in addition warranted an investigation in the second month. In the first month, the performance level indicated the brush was out of control, yet the costs to eliminate the deviation were greater than leaving it alone. It was optimum not to act. In the next month, because the performance had deteriorated even more, the cost to investigate was now less than doing nothing; hence, it was optimum to act.

In explaining how this technique found an inadequate level of performance where the regular system had not, it should be pointed out that this new system has gone one step further than merely relating the control process to a particular worker (as the regular system had done). What has occurred now is a linking of the control process to a worker per given brush, since the losses involved with no investigation and low performance vary according to the brush (brush 612 had the smallest loss per unit, for example). Therefore, because of this connection with particular brushes, it was possible to detect which items were causing problems.

8.4.2 Implementation Costs

Before an organization would implement such a technique, it must first consider the costs for installing and maintaining it. Generally, these costs fall into the following categories:

A. General Orientation

Because of the supervisor's inclusion in the standard-setting and because of his possible lack of knowledge as to some of the mathematics and statistics involved with the technique, it might be beneficial to conduct an initial orientation period of all supervisors. Once this had been done, the only cost thereafter (besides training of new people) would be the time taken by the supervisor to express his belief as to the standard (any time a standard is either set or revised).

B. Differences from EVPI

In Chapter VI, it was shown that the cost of sampling entered the analysis when the expected values of perfect and sample information were calculated. In other words, it was shown that the cost of sampling was balanced by the value of the information received in the sampling.

Nonetheless, in the application of the theory at the organization under study, because of the low cost of sampling and relatively greater computer costs (to calculate various EVSI's), it was concluded that in this case the maximum sample should be taken. In most instances, EVPI will be large enough (to cover cost of sampling), but as shown with brush 612 in the last chapter, if (1) the precision of the prior mean is high and that mean is far from the cutoff point (the indifference point as to the optimum acts), and (2) the loss per brush (PH) is small, then the EVPI will not be large enough. However, since in addition the current sample becomes the prior for the next month, regardless of this difference (EVPI minus CS), the maximum sample is desired. As a result, if in any period the EVPI does not cover the cost of sampling, this difference can be considered a maintenance cost.

C. Computer Cost

One of the benefits of this technique has been the opportunity through the computer to obtain quick results. With this capability has also come the additional cost of using the computer already determined to be $50 an hour. Not considering any computer time needed to compute the mean and standard deviation of the sampling distributions and the respective EVPI value (these costs are considered a part of the cost of sampling), the only computer cost is the time necessary to run the general program which calculates: (1) posterior mean and standard deviation, and (2) expected costs. Therefore, multiplying the time it takes to run the program by the number of items involved gives the most significant implementation cost.

8.5 Suggestions for Future Research

It is believed that this research study has contributed to the existing Accounting literature. In the very first chapter, it was shown how those like Professor Horngren have spoken for the Accounting field to direct itself towards presenting information in terms of the user, in terms of the decision-maker. Following their lead, this work has been one further step in that direction.

For attention to focus directly on the proposed technique, various items were not considered and certain limiting assumptions had to be made. As a result, in the future it would be beneficial in adding to the present model to suggest that some comparison be made of this technique with a more traditional approach. After finding an organization which would accommodate the two groups, it would be interesting to compare among other items the productivity levels of each.

In addition, it would be interesting to consider the behavioral impact of this statistical model versus the more traditional ones.

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A P P E N D I X A

QUESTIONNAIRE GIVEN TO ENGINEER AND SUPERVISOR

Questionnaire: Given to Engineer and Supervisor

Please answer the following:

1. Under ideal conditions, that is, when there is no allowance for learning, shrinkage, waste, machine breakdown, etc. (100% efficiency), how many brushes of type ____ do you believe an average worker should be able to heat-seal in one hour?

   Answer: ____ brushes per hour

2. If a certain percentage factor is thought to reduce this ideal performance level to one representing an average performance level for the average worker, what would that percent be?

   Answer: ____ percent

   Average performance equals ____ brushes per hour (Multiply complement of answer to question two times answer to question one)

3. Because there exists the possibility of adverse or favorable conditions, for a given average worker, there will be fluctuations in the number of brushes heat-sealed per hour above and below the average performance of the average worker. Around this figure (average performance), indicate a range within which you are reasonably sure an average worker will perform 50% of the time.

   Answer: 50% of the time the average worker should heat-seal within ____ brushes per hour on either side of the average performance level.

APPENDIX B

ITEMIZATION OF POSSIBLE REASONS FOR DEVIATIONS AT ORGANIZATION UNDER STUDY

LOST TIME CATEGORIES - PRODUCTIVE LABOR

A. Rework - All productive labor expended on a product which is not authorized on the process specification or operations which must be repeated due to defective workmanship.

B. Spoilage - All productive labor expended for which no standard R.E. hours are earned due to spoilage.

C. Set-up - The difference between standard R.E. hours earned and productive calendar hours expended on set up. - An example might be where direct labor operator assists with, or makes, set up. Another might be where productive operator remains assigned to operate equipment while technician making adjustments to get on set-up.

D. Inventory Time Spent Preparing for and Taking Inventories

E. Cavity - Machine Loss - The difference between standard R.E. hours produced and productive calendar hours expended due to running fewer cavities than that which is basis for cost as defined on manufacturing process specification. Also, this category intended to identify that time lost on multiple machine set-ups with one operator in attendance when number of machines in operation is less than that which is basis for cost as identified on manufacturing process spec.

F. Efficiency

1. Learning - Difference between standard R.E. hours earned and productive calendar hours expended while new employee learning. Note: The duration of learning period will be established for each department and will be issued in near future under separate cover.

2. Teaching - Difference between standard R.E. hours earned and productive calendar hours expended on part of an experienced operator while teaching.

3. <u>Cross-Training</u> - Difference between standard R.E. hours earned and productive calendar hours expended on part of operator whose duration of service exceeds learning period but not previously exposed to present job assignment.

4. <u>Proficiency</u> - Difference between standard R.E. hours earned and productive calendar hours expended attributable to degree of operator skill, capability and/or desire.

5. <u>Non-productive assignment</u> - All productive calendar hours expended on inventory or other clerical activity.

6. <u>Miscellaneous</u> - This category to identify lost time due to power failure, loss of air pressure, employee management or other departmental meeting, first aid treatment or first aid training. Also, this category intended to identify difference in standard R.E. hours earned and productive calendar hours expended due to change in level of process inventory.

7. <u>Assignment change</u> - Difference between standard R.E. hours earned and productive calendar hours expended on the part of direct labor personnel reassigned to department other than home department at Materials Management request. This category is <u>not</u> to be used to identify lost time hours attributable to cross training or filling absentee vacancies initiated by Manufacturing regardless of whether within a department or involving more than one department.

G. <u>Experimental</u> - All time lost on part of productive operators producing samples or attending machine during tool or equipment development.

H. Out of Material - Loss of productive labor hours attributable to Material Management's inability to provide materials.

I. Service - Loss of productive labor hours attributable to Manufacturing's inability to provide materials or service. This category intended to identify only that lost time created by a manufacturing department within the company.

J. Material Problems - Difference between standard R.E. hours earned and productive calendar hours expended due to inferior or defective material. This category intended to identify only that lost time created by inferior or defective materials supplied by outside vendors.

K. Mechanical - Electrical - Mold problems - Difference between standard R.E. hours earned and productive calendar hours expended due to machine, equipment or tool problems.

L. Off Standard - Difference between standard R.E. hours earned and productive calendar hours expended due to a temporary situation requiring that production continue but at a penalty. An example might be substitution of goods with higher labor content requiring new issue of process specification and resultant loss during interim period until honored. Another might be initial production run on a new item where it is mutually agreed by Manufacturing and Engineering to temporarily produce off standard until skills developed. Another example might be change in quality requirement. Another might be breaking of a two deck mold running eight cavities with one operator into two single tier molds to be run four cavities with one operator.

M. Kick-Outs - Loss of productive hours due to inability, for whatever reason, of data processing equipment to accept input data with resultant kick-out and zero earned standard hour generation.

A P P E N D I X C

EXPT COMPUTER PROGRAM FOR INVESTIGATION QUESTION

List of Variables For EXPT Computer Program

U1 = Prior mean
S1 = Prior standard deviation
U2 = Sampling mean
S2 = Sampling standard deviation
U3 = Posterior mean
S3 = Posterior standard deviation

C = Cost of investigation
AK = Cost of correction
AM1 = Time for investigation
AM2 = Time for correction
AM3 = AM1 + AM2
P = Loss per unit
H = Hours in the period

ST = Standard
CTRL = Control limit allowance
AL1 = Lower control limit
AL2 = Upper control limit

EC1 = Expected cost for (A_1, μ_x)
EC2 = Expected cost for (A_2, μ_x)

Cut = Cutoff point
EL = Expected loss for (A_n, μ_x) n=1,2

FZ = FL1 = $\int_{-\infty}^{L_1} f(w)\,dw$ where $f(w) = \frac{1}{\sqrt{2\pi}\,\sigma} \cdot e^{-1/2\left(\frac{w-\mu_1}{\sigma_1}\right)^2}$

$$FL2 = \int_{-\infty}^{L_2} f(w)\,dw$$

$$FT = \int_{-\infty}^{\text{Cutoff point}} f(w)\,dw$$

Prodecural Outline of EXPT Computer Program

Lines 3-50

a) Input values for $FZ = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z} e^{1/2x^2} dx$

b) Preliminary instructions

Lines 100-220

a) Input prior and sampling means and standard deviations

b) Calculate posterior mean and standard deviation

Lines 1000-1044

a) Input: Hours in the period, standard, and control allowance

b) Calculate lower control limit and upper control limit

c) Calculate FZ for L_1 and L_2

Lines 2000-3130

Calculate $EC(A_1,\mu_x)$ and $EC(A_2,\mu_x)$

Lines 5000-5950

All Format statements

Lines 6050-6600

a) Calculate Cutoff point

b) Calculate FZ for Cutoff point

c) Calculate $EVPI = EL(A_1,\mu_x)$ if $\mu_x \leq$ Cutoff point
$EL(A_2,\mu_x)$ $\mu_x \geq$ Cutoff point

Lines 6800-6950

Print out optimum act

Lines 6990-7090

Subroutine to calculate various FZ values

Lines 9000-9390

Data values for FZ

A Sample Run of the EXPT Computer Program

```
RUN
 8K
                    IS AN INVESTIGATION NECESSARY?
    WHAT IS PRIOR MEAN?
?280.
    WHAT IS PRIOR SD?
?12.065

    HAS A SAMPLE BEEN TAKEN?
?YES
    WHAT IS SAMPLE MEAN?
?274.57
    WHAT IS SAMPLE SD?
?22.18
    RECPR. OF POST. VARIANCE EQUALS   .00890254
    POST. MEAN EQUALS    278.7602
    POST. SD EQUALS     10.5985

    HOW MANY HOURS IN PERIOD?
?480.
    WHAT IS THE STANDARD?
?295.
    WHAT IS THE CONTROL ALLOWANCE?
    (INDICATE REPLY AS DECIMAL SUCH AS .1)
?.1

    EXPECTED COST (INV.)
  22.64919396
    EXPECTED COST (NO INV.)
  3.948406088

    CUTOFF POINT EQUALS    255.6738

    EXPECTED VALUE OF PERFECT INFORMATION
  .3914834773

    OPTIMUM ACT AT THIS POINT IS
    "DO NOT INVESTIGATE"

TIME:    1.178 SEC.
```

The EXPT Computer Program

```
03 PROGRAM EXPC
05 DIMENSION A(400)
06 FZ=0.0
08 PIE=3.1416
09 READ, (A(I),I=1,400)
50 PRINT 5500
100 PRINT 5000  $INPUT, U1
110 PRINT 5005  $INPUT, S1
115 PRINT 5520  $INPUT, MN
116 IF (MN .EQ. 3HYES) GO TO 120
117 U3=U1  $S3=S1  $GO TO 1000
120 PRINT 5010   $INPUT, U2
130 PRINT 5015   $INPUT, S2
140 A1=1./(S1**2)
150 A2=1./(S2**2)
160 A3-A1+A2
170 PRINT 5020, A3
180 UK+(U1*A1)+(U2*A2)
190 U3=UK/A3
200 PRINT 5025, U3
210 S3=1./(A3**.5)
220 PRINT 5030,S3
1000 C=14.43  $AK=49.60  $AM1=.5  $AM2=1.25  $P=.0142
1005 AM3=AM1+AM2
1010 PRINT 5035  $INPUT, H
1020 PRINT 5040  $INPUT, ST
1025 PRINT 5045  $PRINT 5530  $INPUT, CTRL
1030 AL1=ST-(CTRL*ST)
1031 L1=AL1+.5  $AL1=L1
1033 CALL CUM(AL1,U3,S3,A,FZ)
1034 FL1=FZ
1040 AL2=ST+(CTRL*ST)
1041 L2=AL2+.5  $AL2=L2
1043 CALL CUM(AL2,U3,S3,A,FZ)
1044 FL2=FZ
2000 V1=-.5*(((AL1-U3)/S3)**2)
2010 V2=-.5*(((AL2-U3)/S3)**2)
2020 V3=S3/((2.*PIE)**.5)
2030 B1=V3*(-EXP(V1))+U3*FL1
2040 B2=V3*((-EXP(V2))+EXP(V1))+U3*(FL2-FL1)
2050 B3=V3*(EXP(V2))+U3*(1. -FL2)
2060 EC1=(C+AK)*GL1+P*AM3*B1
2070 EC1=EC1+C*(FL2-FL1)+P*AM1*B2
2080 EC1=EC1+(C+P*H*AL2)*(1.-FL2)
2090 EC1=EC1+(P*AM1-P*H)*B3
2100 EC2=(P*H*AL1*FL1)-P*H*B1
2110 EC2=EC2+(P*H*AL2)*(1. -FL2)-P*H*B3
```

```
3120 PRINT 5050  $PRINT, EC1
3130 PRINT 5060  $PRINT, EC2
5000 FORMAT (5X, *WHAT IS PRIOR MEAN?*)
5005 FORMAT (5X, *WHAT IS PRIOR SD?*)
5010 FORMAT (5X, *WHAT IS SAMPLE MEAN?*)
5015 FORMAT (5X, *WHAT IS SAMPLE SD?*)
5020 FORMAT (5X, *RECPR. OF POST. VARIANCE EQUALS*, 2X, F10.8)
5025 FORMAT (5X, *POST. MEAN EQUALS*, 2X, F10.4)
5030 FORMAT (5X, *POST. SD EQUALS*, 2X, F10.4)
5035 FORMAT (/,5X,*HOW MANY HOURS IN PERIOD?*)
5040 FORMAT (5X, *WHAT IS THE STANDARD?*)
5045 FORMAT (5X, *WHAT IS THE CONTROL ALLOWANCE?*)
5050 FORMAT (/,5X,*EXPECTED COST (INV.)*)
5060 FORMAT (5X,*EXPECTED COST (NO INV.)*)
5300 FORMAT (/,5X,*CUTOFF POINT EQUALS*,2X,F10.4)
5400 FORMAT (/,5X,*EXPECTED VALUE OF PERFECT INFORMATION*)
5500 FORMAT (20X,*IS AN INVESTIGATION NECESSARY?*,/)
5520 FORMAT (/,5X,*HAS A SAMPLE BEEN TAKEN?*)
5530 FORMAT (5X,*(INDICATE REPLY AS DECIMAL SUCH AS .1)*)
5540 FORMAT (/,5X,*OPTIMUM ACT AT THIS POINT IS*)
5550 FORMAT (5X,*"DO NOT INVESTIGATE"*)
5551 FORMAT (5X,*"INVESTIGATE"*)
5950 FORMAT (10F7.4)
6050 CUT=(P*H*AL1-C-AK)/(P*AM3+P*H)
6051 PRINT 5300, CUT
6052 CALL CUM(CUT,U3,S3,A,FZ)
6055 FT=FZ
6100 V1=-.5*(((CUT-U3)/S3)**2)
6110 V2=-.5*(((AL1-U3)/S3)**2)
6120 V3=S3/((2.*PIE)**.5)
6130 Y1=V3*(-EXP(V1))+U3*FT
6140 Y2=V3*(-EXP(V2)+EXP(V1))+U3*(FL1-FT)
6160 Y3=V3*(EXP(V2))+U3*(1.-FL1)
6500 IF(U3 .GT. CUT) GO TO 6550
6510 EL=(C+AK-P*H*AL1)*(FL1-FT)
6520 EL=EL + (P*H*P*AM3)*Y2
6530 EL=EL + C*(1.-FL1) + P*AM1*Y3
6540 GO TO 6600
6550 EL=(P*H*AL1-C-AK)*FT- (P*H+P*AM3)*Y1
6600 PRINT 5400  $PRINT, EL
6800 PRINT 5540
6820 IF (EC1 .GT. EC2) GO TO 6840
6830 PRINT 5551  $GO TO 6950
6840 PRINT 5550
6950 END
6990 SUBROUTINE CUM(X,U3,S3,A,FZ)
6991 DIMENSION A(400)
7000 Z=(X-U3/S3
7002 IF (Z, LE. 4.0) GO TO 7004
7003 FZ=1.0 $RETURN
7004 IF (Z .GE. -4.0) GO TO 7010
```

```
7005 FZ=0.0 $RETURN
7010 QW=ABS(Z)
7011 IZ=100.*(QW+.005)  $I=IZ+1
7050 IF (Z .GT. 0·0)GO TO 7080
7060 FZ=1.0 - A(I)
7070 RETURN
7080 FZ= A(I)
7090 RETURN
8000 END
8005 ENDPROG
9000 .5000,.5040,.5080,.5120,.5160,.5199,.5239,.5279,.5319,.5359
9010 .5398,.5438,.5478,.5517,.5557,.5596,.5636,.5674,.5714,.5753
9020 .5793,.5832,.5871,.5910,.5948,.5987,.6026,.6064,.6103,.6141
9030 .6179,.6217,.6255,.6293,.6331,.6368,.6406,.6443,.6480,.6517
9040 .6554,.6591,.6628,.6664,.6700,.6736,.6772,.6808,.6844,.6879
9050 .6915,.6950,.6985,.7019,.7054,.7088,.7123,.7157,.7190,.7224
9060 .7257,.7291,.7324,.7357,.7389,.7422,.7454,.7486,.7518,.7549
9070 .7580,.7612,.7642,.7673,.7704,.7734,.7764,.7794,.7823,.7852
9080 .7881,.7910,.7939,.7967,.7995,.8023,.8051,.8078,.8106,.8133
9090 .8159,.8186,.8212,.8238,.8264,.8289,.8315,.8340,.8365,.8389
9100 .8412,.8438,.8461,.8485,.8508,.8531,.8554,.8577,.8599,.8621
9110 .8643,.8665,.8686,.8708,.8729,.8749,.8770,.8790,.8810,.8830
9120 .8849,.8869,.8888,.8907,.8925,.8944,.8962,.8980,.8997,.9015
9130 .9032,.9049,.9066,.9082,.9099,.9115,.9143,.9147,.9162,.9177
9140 .9192,.9207,.9222,.9236,.9251,.9265,.9279,.9292,.9306,.9319
9150 .9332,.9345,.9357,.9370,.9382,.9394,.9406,.9418,.9429,.9441
9160 .9452,.9463,.9474,.9484,.9495,.9505,.9515,.9525,.9535,.9545
9170 .9554,.9564,.9573,.9582,.9591,.9599,.9608,.9616,.9625,.9633
9180 .9641,.9649,.9656,.9664,.9671,.9678,.9686,.9693,.9699,.9706
9190 .9713,.9719,.9726,.9732,.9738,.9744,.9750,.9756,.9761,.9767
9200 .9772,.9778,.9782,.9788,.9793,.9798,.9803,.9808,.9812,.9817
9210 .9821,.9826,.9830,.9834,.9838,.9842,.9846,.9850,.9854,.9857
9220 .9861,.9864,.9868,.9871,.9875,.9878,.9881,.9884,.9887,.9890
9230 .9893,.9896,.9898,.9901,.9904,.9906,.9909,.9911,.9913,.9916
9240 .9918,.9920,.9922,.9925,.9927,.9929,.9931,.9932,.9934,.9936
9250 .9938,.9940,.9941,.9943,.9945,.9946,.9948,.9949,.9951,.9952
9260 .9953,.9955,.9956,.9957,.9959,.9960,.9961,.9962,.9963,.9964
9270 .9965,.9966,.9967,.9968,.9969,.9970,.9971,.9972,.9973,.9974
9280 .9974,.9975,.9976,.9977,.9977,.9978,.9979,.9979,.9980,.9981
9290 .9981,.9982,.9982,.9983,.9984,.9984,.9985,.9985,.9986,.9986
9300 .9987,.9987,.9987,.9988,.9988,.9989,.9989,.9989,.9990,.9990
9310 .9990,.9991,.9991,.9991,.9992,.9992,.9992,.9992,.9993,.9993
9320 .9993,.9993,.9994,.9994,.9994,.9994,.9994,.9995,.9995,.9995
9330 .9995,.9995,.9995,.9996,.9996,.9996,.9996,.9996,.9996,.9997
9340 .9997,.9997,.9997,.9997,.9997,.9997,.9997,.9997,.9997,.9998
9350 .9998,.9998,.9998,.9998,.9998,.9998,.9998,.9998,.9998,.9998
9360 .9998,.9998,.9999,.9999,.9999,.9999,.9999,.9999,.9999,.9999
9370 .9999,.9999,.9999,.9999,.9999,.9999,.9999,.9999,.9999,.9999
9380 .9999,.9999,.9999,.9999,.9999,.9999,.9999,1.0,1.0,1.0
9390 1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0
```

A P P E N D I X D

SAMPLE OBSERVATIONS FOR THE THREE BRUSHES UNDER STUDY FOR DECEMBER (1971) AND JANUARY (1972)

Brush 632

December (n=183)

288,256,288,276
289,268,289,265
289,289,289,289
289,289,289,290
288,276,288,276
288,228,209,234
288,270,288,270
289,265,289,265
288,270,288,270
289,265,289,265
288,273,288,273
289,265,289,265
288,264,288,264
289,289,289,291
288,276,288,276
289,265,289,265
288,264,288,264
288,270,270
289,265,289,265
289,289,289,289
288,264,288,264
216,216,216
289,289,289,296
289,329,265
288,168,180,288
289,265,289,265
288,264,288,264
289,265,289,265
288,264,288,282
289,265,289,265
288,264,288,264
289,265,289,265
288,264,288,264
277,264,289,265
288,264,288,300
289,265,289,265
289,265
288,270,288,270
289,265,289,265
289,264,288,288
232,204,277,204
276,270,288,270
270,216,288,212
288,270,289,275

January (n=160)

289,270,289,280
288,288
289,289
288,270,288,270
288,276,288
276,270,288,270
288,270,288,270
289,289,289,300
252,252
289,289,290
288,270,288,270
289,289,289,303
288,270,288,270
288,276,293,276
289,289,289,297
288,276,288,276
288,288,288,288
288,276,288,276
288,288,288,288
288,276,288,276
288,276,288,276
288,276,288,276
288,288,288,288
288,276,288,276
165,288,288,288
288,276,288,276
288,270,288,270
288,276,288,276
288,276,288,273
321,289,289
289,289,289,321
288,270,288,270
289,289,289,289
290,286
288,270,288,270
289,307,313,289
289,269,289,269
288,288,288
288,270,288,270
289,289,307,303
288,272
289,289
288,270,288,270
289,289,307,303

276,264,288,276
288,264,288,288
288,270,289,209

$\bar{\bar{x}} = 274.57$

$\sigma(\bar{\bar{x}}) = 22.18$

$\bar{\bar{x}} = 283.96$

$\sigma(\bar{\bar{x}}) = 13.98$

Brush 3982

December (n=90)

289,289,289,303
289,289,289,308
289,289,312
234,264,288,222
289,289,289,303
151,162,201,289
289,289,289,303
289,289,289,300
289,289,289,316
289,289,289,321
288,288,288,288
291,289,289,299
288,290,289,297
289,289,289,321
289,289,289,300
289,289,289,291
289,289,289,316
289,289,289,291
289,289,289,326
289,289,322
289,289,289,321
288,264,216,209
289,289,289,321

$\bar{x} = 285.64$

$\sigma(\bar{x}) = 28.50$

January (n=118)

289,289,289,321
216,252,252,274
289,289,244,321
289,289,289,321
289,289,289,295
289,289
289,289,289,321
289,289,289,289
289,289,289,321
288,288,288,288
289,252,289,300
289,289,289,321
289,289,289,321
288,288,192
289,289,289,291
289,289,289,321
289,288
289,289,289,321
288,288,288,288
288,288,288,288
289,289,289,321
289,289,289,321
289,216,289
289,314,289
288,216,288
289,289,289,321
289,289,289,321
288,288
289,289,289,321
288,288,288,288
289,289,289,321
288,288,288,288

$\bar{x} = 289$

$\sigma(\bar{x}) = 20.24$

Brush 612

December (n=48)

216,260,216,180
216,198,216,196
216,216,216,216
288,288,252,216
168,120,191,216
216,216,216
216,198,234,191
216,198,234,216
180,225,194
216,216,216,210
216,216,216
228,252,132
210,210,216,216

$\bar{\bar{x}} = 212.94$

$\sigma(\bar{\bar{x}}) = 29.06$

January (n=76)

189,180,180,180
189,180,180,180
230,230,231
198,180,180,180
216,180,180,180
198,198,120
162,162,216
180,216,216,216
198,198,216,189
164,138
228,180,219,198
198,288
216,180,216,198
220,220,240,223
216,180,180,216
156,216
220,216,220,180
252,252,288,267
144,180,216,216
216,198,234,216
180,144
180,144,264

$\bar{\bar{x}} = 200.59$

$\sigma(\bar{\bar{x}}) = 32.02$